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Promoting Higher-Order Thinking Through Teacher Questioning: a Case Study of a Singapore Science Classroom

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Abstract

This qualitative case study employed an existing framework (Chin, 2006) to examine teacher questioning strategies that promote students' higher-order thinking in science. The study explored the instruction of an experienced science teacher and a 10th grade Chemistry class that he taught in a Singapore school. Our methods included lesson observations, questionnaire and interviews. We found that the teacher frequently applied non-evaluative follow-up moves and supportive follow-up moves to student responses in episodes that students appeared to engage in science thinking through classroom talk. Non-evaluative follow-up moves included *withhold evaluations, restatements* and *reformulations*. Supportive follow-up moves were *prompts* that required students to elaborate or clarify their answers and to justify reasoning. Interview findings further suggested that the teacher prompts helped students to build on their science ideas and engaged them in thinking reflectively. We discussed implications for classroom practice to help teachers work towards the goal of nurturing lifelong learners.

Introduction

Helping students develop lifelong learning skills is an important educational outcome for the 21st century classroom (Partnership for 21st Century Skills, 2006). Lifelong learners are able to take charge of one's own learning and actively engage in the learning process to generate questions, brainstorm ideas, solve problems, and construct meaning and knowledge (Little, 2007). Lifelong learning demands self-regulation skills but also critical thinking competencies such as higher-order thinking skills. When students exhibit higher-order thinking, they are able to apply their knowledge, synthesize different information and evaluate science ideas and hypotheses (Hurd, 1999). In Singapore, major educational initiatives emphasize the teaching of self-regulated learning and higher-order thinking skills for grade K to 12 curriculum (e.g. *Thinking Schools, Learning Nation,* MOE, 2005). Therefore, schools and teachers are urged to provide more opportunities for learner engagement and deep thinking processes in their local classroom practices.

Teacher questioning can be a useful and practical means for teachers to work towards the goal of developing lifelong learning skills among students. Over the last decade or so, research has shown that students' conceptual understandings in science are developed within social contexts in the classroom, and that students' understandings and thinking about science can be enhanced when teachers facilitate an interactive discourse through classroom questioning (e.g. Chin, 2006, 2007; Mortimer & Scott, 2003; Scott, Mortimer, & Aguiar, 2006; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Wells & Arauz, 2006). While research on teacher questioning has been widely studied, the application of existing questioning frameworks to examine science instruction for ways in which teacher follow-up discourse moves shape students' higher-order thinking in science has been less extensive. Moreover, teacher-student classroom talk interactions are complex and teacher questioning strategies may differ considerably across classroom contexts. Arguably, teacher questioning strategies or approaches that might facilitate students' deep cognitive processes in science learning remain under-explored.

We seek to address this gap by exploring the actual practice of an experienced science teacher based on an existing analytical framework (Chin, 2006) and illuminating questioning strategies or discourse moves that promote students' higher order thinking in science. We hope that our findings can contribute to the growing literature on effective classroom conversations in science, particularly on how teacher questioning can support students' learning in Singapore. The implications from this study may also lead to a broader understanding of classroom discourse and the expansion of ways of speaking such as the teacher discourse moves that provide opportunities for supporting students' learning and developing their skills for critical thinking, so as to achieve the curriculum goal of lifelong learning.

Teacher Questioning

Teacher questioning plays an important role in instruction. Teachers pose questions frequently, often for reasons such as to stimulate interest or curiosity, to generate students' knowledge claims, and to check students' knowledge comprehension (Dillon, 1984). It is also widely established that instructional questions promote students' cognitive processes at different levels and complexity (Bloom, 1956; Blosser, 1991; Costa & Khallick, 2000; Wragg & Brown, 2001). According to Bloom (1956), questions can elicit six levels of cognitive processes: *recalling*, *understanding*, *applying*, *analyzing*, *synthesizing* and *evaluating*. Questions pitched at the cognitive level of *recalling* and *understanding* scientific information are called lower-order thinking questions. Higher-order thinking questions, in contrast, are questions pitched at a cognitive level of *applying*, *analyzing*, *synthesizing* or *evaluating* scientific knowledge. Blosser (1991) referred to two primary question types: closed and open questions. Closed questions have one predetermined answer or a limited number of acceptable answers. In contrast, open questions elicit a wide range of possible responses rather than one or two "right answers" and often have the potential to stimulate higher levels of thinking processes such as evaluating scientific knowledge.

There are mixed views about whether higher-order thinking questions necessarily provide better learning for students (Arends, 1994). Some studies reported that higher-order thinking questions and open questions can foster deeper conceptual thinking among students (Chin, 2004; Yip, 2004). For instance, the study done by Yip (2004) suggested that higher-order thinking questions induced conceptual change in students when they learned science, challenged and extended students' thinking to resolve inconsistent views, and helped students apply a newly acquired concept to different situations. However, researchers have also counter-argued that higher-order thinking questions may not necessarily promote the level of thinking intended for the students to generate the responses as there is incongruence between the cognitive levels of the questions and student thought levels (Dillon, 1982; Berliner; 1984; Dantonio & Beisenherz, 2001). Given that teachers spend most of their time asking closed or low-level thinking questions (Wilen, 1991), it might perhaps be helpful to pay closer attention to the teacher-student interactions leading from the initial question and the discourse patterns or strategies that might facilitate deeper thinking among students.

In the science classroom, teacher questioning is typically a recitation or a “triadic dialogue,” described as a three-part exchange where the teacher initiates by asking a question, a student reacts to make a response, and then the teacher evaluates the answers (Lemke, 1990). In Mehan’s (1979) terms, this three-part exchange is known as the IRE discourse – initiation (I), response (R) and evaluation (E). The triadic dialogue, or IRE, is helpful for reviewing factual materials and directing the discourse (Lemke, 1990). During such an exchange, the teacher decides what a correct response is and what is not. The teacher “evaluation” move allows him/her to transmit the appropriate scientific knowledge to students as “incorrect information can be replaced with the right answers” (Newman, Griffin, & Cole, 1989, p.127). In this way, the teacher also controls and manages the flow of the talk.

The IRE approach of questioning is, however, heavily criticized for its lack of opportunities for stimulating students’ higher order thinking. This discourse practice is labeled as a “transmissive” approach, whereby the students relied on the teacher for information and which offered little opportunity for the construction of meaning in the social context of the classroom (Orsolini & Pontecorvo, 1992). In addition, the IRE discourse was perceived to “have restrictive effects on students’ thinking as students’ responses remained brief and teacher-framed” (Chin, 2006, p. 1316). However, researchers also noted that the “third move” of the IRE can potentially scaffold students’ extension of knowledge and thinking when replaced with appropriate discourse strategies (Chin, 2006; Nassaji & Wells, 2000). In such instances, the teacher’s response to a student’s answer is not limited to an evaluation. For instance, the teacher can pose another question to elicit a response from students. When this question is proffered, the teacher once again has the same range of options available for making another follow-up move. Dubbed the IRF exchange—initiation (I), response (R), and follow-up or feedback (F)—this interactional pattern can be extended to offer a chain of teacher-students exchanges that ultimately leads to a discussion-based discourse.

The IRF discourse offers benefits of engaging students in active learning and helping them develop essential skills for lifelong learning. When teachers shift the IRE questioning towards a more interactive IRF discourse, students can take on a more active role in learning science through thinking about their answers and questions (e.g. Chin, 2007; Nassaji & Wells, 2000). Moreover, teacher prompts and talk scaffolding in an IRF discourse encourage students to predict; to venture their ideas more spontaneously; to resolve discrepancies; to ask questions; and, to give more elaborative explanations which can help them adopt learning approaches and skills essential for lifelong learning (Chin & Brown, 2000). Research has further suggested that the variations that stem from the IRF offer potential for dialogic interactions (Mortimer & Scott, 2003) and knowledge co-construction (Roth, 1996).

To engage students in deeper thinking through a more interactive IRF discourse, van Zee and Minstrell (1997) proposed the “reflective toss.” Van Zee and Minstrell examined the discourse sequence of physics lessons using a three-part structure: a student statement, a teacher question, and additional student statements. They purposefully explored the follow-up moves of the IRF questioning for a “reflective toss” where the teacher asked a question in response to a student statement and throws the responsibility for thinking back to the student. Van Zee & Minstrell found that the teacher can promote student reflection when his responses to the students (a) make students express their meanings more explicitly, (b) consider a variety of students’ views in a neutral manner and (c) encourage students to monitor the discussion and their own thinking.

Likewise, Chin (2006) offered the "questioning-based discourse" to help teachers build a more interactive IRF discourse to promote students' deeper thinking about science. Her framework explored both the cognitive and conceptual change in the discourse by analyzing students' cognitive processes in relation to the teacher's utterances within the teacher-student talk exchanges. The framework focused on four aspects of classroom discourse namely the science content, the type of utterances, the thinking elicited, and the interaction pattern. The science content referred to the science concepts or ideas while the type of utterances described the form of the utterance such as a question, answer or comment. The thinking elicited represented the type of cognitive process associated with a student's response. The interaction pattern described the links between students' responses and reactions to questions initiated by the teacher, the type of feedback given in relation to the purpose of the question, as well as the function of the utterance.

Based on findings using this framework, Chin (2006) recommended the following questioning strategies that can stimulate productive thinking in students in Singapore science classrooms. First, for correct student answers, the teacher may affirm and reinforce the answer and then move on to further exposition and direct instruction. Second, for a mixture of incorrect and correct answers, the teacher can accept the response and ask a series of related questions that build on previous ones to probe or extend conceptual thinking. Last, for incorrect answers, the teacher may provide an explicit correction followed by further expounding of the normative ideas or a neutral comment followed by reformulation of the question or challenge via another question.

However, the ways to employ IRF questioning for students' thinking may vary widely across classrooms as teacher-student classroom talk exchanges are complex interactions situated in different social contexts. To our understanding, the use of existing questioning frameworks, such as those discussed above, to examine science instruction for ways in which teacher follow-up discourse moves shape students' higher-order thinking in science has been less extensive. In this study, we seek to address this gap by exploring the actual practice of an experienced science teacher based on an existing questioning framework (Chin, 2006) and illuminating questioning strategies or discourse moves that promote students' higher-order thinking in science learning.

School and Class Settings

The school setting in this study was a co-educational government school in Singapore which offered grade 7 to 10 curriculum. The school has a student population of around 1,600 and students were high academic achievers in terms of national assessment scores. The first author approached the school and invited science teachers who have at least five years of teaching experience to participate in the research study. The rationale for approaching experienced teachers was that their teaching expertise might be likely to provide for robust and richer discussions in the classroom. One teacher, Mr. Shaun, agreed to participate in this study. Shaun had industry work experience for several years as a chemist before joining the teaching profession. With his professional background and teaching experience of six years in secondary science, Shaun was also one of the two Senior (Specialist) teachers in the school's science faculty. The class that Shaun taught was a 10thgrade class. The class comprised a total of 33 boys and girls, and all the students were of Chinese ethnicity.

Methodology

We employed a descriptive case study approach (Yin, 1984) to derive an in-depth understanding on how one experienced teacher provided talk scaffolding for a 10th-grade class that he taught. Our methods of data collection included lesson observations, student questionnaire and interviews with the teacher and the students. The data collection was conducted over a semester and the process lasted for five weeks. The lesson observations were planned to cover the complete instruction of one science unit. The first author observed and video-recorded all the lessons. A total of five lessons were recorded. The first two lessons served as familiarization lessons to allow the students to become accustomed to the presence of the video recorder and the observer (first author). Table 1 provides background information for the three formally video-recorded lessons.

Table 1. Background Information on the Lessons

Lesson	**1**	**2**	**3**
Topic	**Metals – Extraction of Iron**	**Ammonia – Structure of the ammonia molecule**	**Ammonia – The Haber process**
Lesson objectives	Pupils should be able to: • understand the processes and chemical reactions involved in the extraction of iron • describe the physical properties of alloys	Pupils should be able to: • understand what ammonia is and its properties • understand that ammonia is commonly encountered in their daily life • identify ammonia gas using various methods	Pupils should be able to: • understand the meaning of a reversible reaction • know the sources of hydrogen and nitrogen for the manufacture of ammonia

At the end of each lesson, students were asked to complete a short questionnaire. The questionnaire (see Figure 1) comprised of open-ended questions to elicit brief comments from students regarding their learning for each lesson. The student questionnaire was intended to facilitate the selection of lesson episodes for further analysis and to provide supplementary findings for data triangulation with the interview data.

The first author also conducted interviews with the teacher and selected students. The teacher interviews included: (a) an initial interview to find out the topic(s) that he intended to teach, and the ways in which he intended to use questioning to support students' learning and (b) subsequent interviews after each lesson to elicit commentary regarding the teacher's use of questions and feedback during instruction. Individual interviews were also conducted with selected students after each lesson to elicit their views regarding their learning during the classroom conversations with the teacher. The criteria for the selection included: (a) a student who has engaged in a rich conversation with the teacher, as identified from the video recordings and (b) a student who has given useful comments from the questionnaire that is related to any of the lesson episodes identified from the questionnaire. The interviews were semi-structured which included open-ended questions to allow the students to share information regarding their learning experiences in class with the teacher. A total of six students participated in the interviews.

Data Analysis

We applied discourse analysis to study the language in use from the social interactions between the participants (Hicks, 1995) and our analyses focused on the identification of questioning strategies that promoted students' conceptual thinking during classroom talk. We conducted two stages of analyses. In the first stage of analysis, we examined data from the student questionnaire to look at what students reported on their experiences and learning from the lessons. The results from the questionnaire provided indications on the key learning points about the lessons which facilitated our identification of episodes for the second stage of analysis. In the second stage of analysis, we examined selected lesson episodes that involved teacher-student dialogues or discussion from video transcripts. We employed Chin's (2006) framework as our analytical lens. Figure 1 shows a sample analysis of a lesson episode. The features of analytical grid include (Chin, 2006, p.1322):

(1) The "Turn" column provides the sequence order to the speakers' utterances.
(2) The "Speaker" column shows the participant, the teacher or students, making the utterance(s).
(3) The "Utterances" column shows the speech content.
(4) The column titled "Move" indicates the form of the utterance, whether it is a teacher-initiation (I), student response (R) or teacher follow-up (F).
(5) Entries in the column titled "Type of utterance" indicate whether the utterance is in the form of a question, answer, statement, comment, or a combination of more than one type. A statement refers to further content-related proposition made by the teacher whereas a comment is an evaluative or neutral utterance given by the teacher in response to a student's reply to his question. These three components (namely, move, purpose, and type of utterance) represent the "interactive" aspect of the discourse.
(6) The column labelled "Purpose of utterance" represents the purpose or function in that discourse move (e.g., accept, elicit, reply, probe). In this study, we use the term *prompt* which refers to a follow-up question from the teacher in response to the student answer. Thus, whenever the discourse move includes a question that functions to elicit or probe a student response, it will be coded with a *prompt*.
(7) The final column, entitled "cognitive process," indicates the thinking processes associated with students' utterances. The cognitive categories reflected the type of thinking that was elicited. These included mere recall, as well as the higher-order thinking processes such as hypothesizing, predicting, explaining, interpreting, and making conclusions. As indicated by Chin, such analysis was inferential in nature, and based on what was known about the classroom context as it is not possible to gain direct access to the minds of the students.

Turn	Speaker	Utterance	Move	Type of utterance	Purpose of utterance	Cognitive process
104	T	… I give you a scenario… there is [an] acid spill … [and] you want to neutralize the acid… What will you choose? 1. … magnesium metal. 2. … solid calcium carbonate. 3. … aqueous sodium hydroxide. And what is the reason for choosing that particular choice?	I	Q		-
⋮						
110	T	… Why you choose aqueous sodium hydroxide?(3)	I	Q		-
111	Peter	Stronger alkali.	R	A		Explain
112	T	Stronger alkali. That is the reason? Any other possible reasons?	F-I	S-Q	Restate, Prompt (clarify), Prompt (elaborate)	-
113	Monica	Magnesium very reactive and then will react vigorously with the acid.	R	A		Reason
114	T	But sodium hydroxide also can react vigorously with acid right?	F	Q	Prompt (elaborate)	-
115	Monica	But the products formed can easily be removed.	R	A		Reason
116	T	= the products formed can easily be removed. You mean the products formed between aqueous sodium hydroxide and sulphuric acid is easily removed. What are the products formed?	F-I	S-Q	Restate, Prompt (clarify), Prompt (elaborate)	-
117	Monica	Sodium sulphate and water.	R	A		Apply
118	T	Sodium sulphate and water. And sodium sulphate is a soluble salt and probably will dissolve in water. Elroy, why you choose calcium carbonate.	F-I	S-Q	Restate, Explain, Prompt (redirect)	-
119	Elroy	Sorry I regret.	R	A		-
120	Class	Laughter				
121	T	… Nevermind. Can you tell us your original intention why you choose calcium carbonate.	F-I	C-Q	Accept, Prompt (justify)	-
122	Elroy	Because just now I forget the calcium sulphate is insoluble in water. If we assume that it is soluble in water, then I think that calcium carbonate is better than sodium hydroxide. Because firstly the calcium carbonate is cheaper than sodium hydroxide.	R	A		Reflect
123	T	So he thinks about the price.	F	C	Accept	-

Figure 1. Sample Analysis Based on Chin's Analytical Framework

Findings

Results from Student Questionnaire

From the student questionnaire, we noted that the student responses to Item 2 were most relevant to inform our selection of the lesson episodes for discourse analysis. The questionnaire item invited students to comment on something the teacher said that made them think. As shown in Table 2, the student responses revealed several teacher questions from each lesson that stimulated thinking in science.

Table 2. Student Responses to Questionnaire Item 2

Lesson 1	Lesson 2	Lesson 3
The teacher • posed the real life application question (13) • asked whether molten iron will be oxidized in the Basic Oxygen Furnace (BOF) or not (10) • asked why carbon is added to the molten iron after removal (3) • asked how pure iron is obtained (2) • asked where do the impurities come from (2) • asked if calcium oxide can be replaced with other suitable substance or not (1)	The teacher • asked how to draw the 3D structure of ammonia (5) • asked the purpose of making ammonia (3) • asked if the reaction, $NH_3 + HCl \rightarrow NH_4Cl$, is a redox reaction (3) • asked why water can act as acid and base (1) • asked the class how to draw the model of NH_4^+ (1)	The teacher • asked what is meant by an equilibrium (11) • asked what is a reversible reaction (4) • asked what can students infer from 'cracking of petroleum' (3)

Note: Frequency of student responses is indicated in parentheses.

The results enabled us to identify three key lesson episodes that showed substantial teacher-student talk exchanges extending from IRF teacher questioning. These included:

- Episode 1 – teacher-student talk exchanges on the "real life application" problem (also called the acid spill problem)
- Episode 2 – teacher-student talk exchanges on "what is a reversible reaction"
- Episode 3 – teacher-student talk exchanges on "what can students infer from 'cracking of petroleum'"

The teacher-student talk exchanges in these episodes were further examined using Chin's (2006) analytical framework.

Results from Analysis with Chin's (2006) Questioning Framework

The analysis of the lesson episodes revealed frequent non-evaluative teacher follow-up moves and supportive teacher follow-up moves. Table 3 summarizes the teacher follow-up moves across the three episodes. The non-evaluative teacher follow up moves comprised of the following: "withhold evaluation;" "restate;" and "reformulate." In the "withhold evaluation" move, the teacher avoided responses that explicitly assessed the correctness of the student answer. Instead, he provided a subtle affirmation such as "okay" and "yeah." The "restate" move referred to the teacher restating the student answer without any correction. In the "reformulate" move, the teacher paraphrased the student answer to make the meaning clear.

Table 3. Summary of Follow-Up Moves that Facilitate Students' Thinking in the Lesson Episodes

Episode 1 Turn	Teacher follow-up moves	Students' learning or thinking facilitated
112	Withhold evaluation/Restate Prompt: Clarify Prompt: Demand elaboration	• Student generated alternative reasons for choosing "aqueous sodium hydroxide"
114	Withhold evaluation Prompt: Demand justification	• Student related answer back to the focal issue • Student provided a counter-argument
116	Withhold evaluation/Restate Prompt: Clarify Prompt: Demand elaboration	• Student provided further information or details on the "products formed"
121	Withhold evaluation Prompt: Demand justification	• Student reflected on why the answer was incorrect
Episode 2 Turn	**Teacher follow-up moves**	**Students' learning or thinking facilitated**
062	Withhold evaluation Prompt: clarify	• Student improved on the statement
066	Withhold evaluation Prompt: Redirect Prompt: Demand elaboration	• Student further explained the term "product"
068	Withhold evaluation Prompt: Demand elaboration	• Student compared two equations
070	Accept Prompt: Clarify	• Student made explicit about the directions of the arrows
072	Comment Prompt: Focus Prompt: Redirect	• Student related answer back to the focal issue • Student contributed alternative ideas
076 – 082	Comment Series of Prompts: clarify	• Student improved on statement (the meaning of "it")
Episode 3 Turn	**Teacher follow-up moves**	**Students' learning or thinking facilitated**
009	Reject/Explain Prompt: Demand elaboration	• Student reconsidered the content of crude oil
013	Reject/Explain Prompt: Demand elaboration	• Student expanded the idea of hydrocarbon
015	Withhold evaluation/Restate/ Accept/Reformulate Prompt: Focus	• Student rethink the term "petroleum"
017	Praise Prompt: Demand elaboration	• Student provided further explanation on the term "breaking"
021	Withhold evaluation Prompt: Clarify Prompt: Demand elaboration	• Student generated an example of hydrocarbon
023	Praise/Restate/Reformulate Prompt: Demand elaboration	• Student related the cracking of petroleum with an example of a hydrocarbon
025	Prompt: Clarify	• Student rectified answer
031	Accept Prompt: Demand elaboration	• Student reflected on the application of the analogy
033	Withhold evaluation/Restate Prompt: Demand elaboration	• Student made comparison between whole and shattered glass
035	Withhold evaluation/Restate Prompt: Focus	• Student related answer to the scientific term "cracking"
038	Withhold evaluation/Restate Prompt: Clarify	• Student improved the meaning of answer ("smaller molecules")

The supportive teacher follow-up moves comprised *prompts* or follow-up questions which were commonly paired up with the non-evaluative teacher follow-up moves. The *prompts* however varied in terms of its functions and appeared to promote different student cognition. First, the "clarify" prompt was widely applied across the three lesson episodes. This prompt referred to follow-up move where the teacher posed a question to check on the meaning of a student's answer. This teacher follow-up move helped students to clarify the meaning of their responses and encouraged them to rethink and refine their answers. The talk exchanges between Shaun and student Jiayi in episode 3 evidently demonstrate this point:

072	*T*	*…Anyone would like to help? To put in words, nice words, what is a reversible reaction? (2) Jia yi?*
073	*Jia yi*	*A reversible is a reaction whereby the reactants erh.*
074	*T*	*=Yar, reactants, what happened to the reactants?*
075	*Jia yi*	*And they formed into products and it can changed from the products back into the reactants.*
076	*T*	*Ok, you almost got it. But you use the word 'it' and I don't know what you are referring to. You use the word I, T, 'it'. Where the reactants react to form?*
077	*Jia yi*	*The products.*
078	*T*	*Products and at the same time?*
079	*Jia yi*	*The product.*
080	*T*	*The product can what?*
081	*Jia yi*	*Can form back.*
082	*T*	*In this case… the products can?*
083	*Jia yi*	*Can breakdown back into reactants.*
084	*T*	*=Can breakdown back into reactants. A reversible reaction is a two-way reaction…*

In the talk exchanges, student Jia yi attempted to describe a reversible reaction following Shaun's question (turn 072). Although her answer was incomplete, Shaun did not evaluate but provided "clarify" prompts to guide the student in improving on the answer. His prompts included: "what happened to the reactants?" (turn 074), what does "it" referred to (turn 076) and what happened to the products at the same time (turn 078 and 080). These prompts helped Jia yi to generate an answer with a more precise meaning and appeared to promote deeper thinking about the science idea.

Interview findings with Jiayi supported our assertion. During the interview, Jia yi said, *"I think [Mr Shaun] was trying to guide me along… I gave vague terms like 'it' or half sentences like 'the products' then he… ask me and I will… continue on, actually makes me elaborates on my point, and my expression is clearer."* Moreover, the student commented that the "step by step thinking" that she learned from the lesson can be used to solve future problems:

> I think if we meet with similar cases in the future… like we … don't know what a reversible reaction is, then we try to apply our past knowledge and go step by step thinking. Apply our past knowledge to help us roughly get the idea of what the new term or whatsoever is he referring to.

Also widely used in the lesson episodes were the "demand elaboration" and the "demand justification" prompts. In a "demand elaboration" prompt, the teacher question or response required the student to elaborate on their ideas or answers. The "demand justification" prompt involved the teacher asking the "why" question. This prompt required students to provide reasons or rationale for their answers which enabled the teacher to probe into student's reasoning. The talk exchanges between the teacher and two students in episode one showed how these teacher follow-up moves facilitated students' thinking:

Turn	*Speaker*	*Utterance*
104	*T*	*… I give you a scenario… there is [an] acid spill … [and] you want to neutralize the acid… What will you choose? 1. … magnesium metal. 2. … solid calcium carbonate. 3. … aqueous sodium hydroxide. And what is the reason for choosing that particular choice?*
⋮		
113	*Monica*	*Magnesium very reactive and then will react vigorously with the acid.*
114	*T*	*But sodium hydroxide also can react vigorously with acid right?*
115	*Monica*	*But the products formed can easily be removed.*
116	*T*	*= the products formed can easily be removed. You mean the products formed between aqueous sodium hydroxide and sulphuric acid is easily removed. What are the products formed?*
117	*Monica*	*Sodium sulphate and water.*
118	*T*	*Sodium sulphate and water. And sodium sulphate is a soluble salt and probably will dissolve in water. Elroy, why you choose calcium carbonate.*
119	*Elroy*	*Sorry I regret.*
120	*Class*	*Laughter*
121	*T*	*… Nevermind. Can you tell us your original intention why you choose calcium carbonate.*
122	*Elroy*	*Because just now I forget the calcium sulphate is insoluble in water. If we assume that it is soluble in water, then I think that calcium carbonate is better than sodium hydroxide. Because firstly the calcium carbonate is cheaper than sodium hydroxide.*
123	*T*	*So he thinks about the price.*
124	*Elroy*	*Think of the acid in a large area, right then if we use sodium hydroxide we will require a large amount. Then secondly because we can spit excess amount of calcium carbonate onto acid and if we spit, if we spit excess aqueous sodium hydroxide, then it will be harmful because it is a strong alkali. So it is difficult for us to judge how much reactants you need to neutralize the rest. So by judging these two, I choose the calcium carbonate. The problem is calcium carbonate will not dissolve in water so if we choose the powdery form of calcium carbonate, it will also work.*
125	*T*	*… what to choose actually depends on what you want… so you must consider all factors …*

In the talk exchanges illustrated above, Shaun posed a question on an acid spill problem to the class. To answer this question, students were required to select one of the three given options (magnesium metal, solid calcium carbonate and aqueous sodium hydroxide) for neutralizing the acid, and they also have to provide reasons for their selection. In turn 113, student Monica attempted to justify her answer based on the high reactivity of the metal. Here, Shaun responded to her answer by using a "demand justification" prompt to counter-argue that other substances were reactive too (turn 114). This prompt helped the student rethink about her reasoning and prompted her to consider another reason – the solubility of the substances (turn 115). However, her explanation "the products can be easily removed" did not clearly presented this meaning. In turn 116, the teacher used a "demand elaboration" prompt to help the student think of the products formed between sodium hydroxide and sulphuric acid. This prompt enabled Monica to make her point on the solubility of the substances more clearly. In another instance, the teacher also made a "demand justification" prompt to student Elroy to justify his mistake (turn 121) which facilitated the student to analyze and explain what was wrong with his thinking.

The interview findings also provided supporting evidence that the teacher prompts promoted deeper thinking in science. Interview with Monica after the lesson suggested that she had gained conceptual understanding of neutralization reaction:

> I think it's more of an understanding. Because in a neutralization reaction, water will be formed usually… the sodium ions will react with the sulphate ions … you get sodium sulphate … hydroxide and H^+ in the acid will form water.

In the interview with student Elroy, he said that the teacher questions provided him an opportunity to articulate out his conceptual thinking and helped him to realize what went wrong with his answer. Evidently, the supportive teacher follow-up moves encouraged both students to think reflectively on their conceptual understanding.

Discussion

Consistent with earlier research reports (Dillon, 1994), our results firstly suggest that non-evaluative teacher follow-up moves in an IRF discourse can offer knowledge affirmation for students and help them gain understanding of subject matter. This was clearly evident from our findings where the teacher frequently restate or reformulate students' answers. Restatements not only affirm students' responses without an explicit evaluation (Chapin, Anderson & O'Connor, 2003) but also provide a form of "amplification" where the information can be made available to all (Edwards & Mercer, 1987). Likewise, by making a reformulation, the teacher adopted a subtle approach to alter a student's answer in a way to make the meaning more explicit. Although reformulations take the form of a non-explicit evaluation, this follow-up move can also be used to establish the curricular material as appropriate classroom knowledge (Lemke, 1990). Moreover, a reformulation helps to scaffold both students' thinking and linguistic learning by "allow[ing] students, particularly those with weak language abilities and who may have difficulties in verbalizing their thoughts, the opportunity to co-construct response with their teacher and peer" (Chin, 2006, p.1336).

Secondly, our assertion concurs with Chin and Brown's (2000) argument that supportive teacher follow-up moves or verbal prompts provided by teachers in an IRF discourse are likely to help students develop deep thinking processes such as thinking reflectively and self-evaluating their answers. As Chin & Brown maintained, "deep thinking processes are sometimes latent in students and are manifested only under optimal conditions such as through another person's scaffolding, prompting, or probing as a result of the interaction between the students' dispositions and situational circumstances" (Chin & Brown, 2000, p.133). Moreover, when students work towards restructuring their ideas, they become motivated in changing their existing ideas and engaged in more self-regulated construction of meaning (ibid). Thus, giving students the opportunities to refine their ideas and to reflect on their thinking during classroom discourse can help them undertake a self-directed approach to assess their existing ideas (Gunstone, 1994) and thereby developing cognitive skills necessary for them to be lifelong learners.

Thirdly, our findings also suggest that the IRE or IRF discourse can be extended to a discussion-based discourse when the teacher response to the student answer (the third move of the IRF exchange) comprised couplets of non-evaluative teacher follow-up moves with supportive teacher follow-up moves. As our findings have shown, non-evaluative teacher follow-up moves (such as a restatement or reformulation) allowed the teacher to avoid immediate assessment of the student answer and to avoid an early closing of the conversation. Moreover, the supportive teacher follow-up moves enabled the teacher to extend the dialogue or conversation as each prompt introduces a recurring IRF chain, generating interaction patterns characterized by a series of IRF or the extended IRFRF chains (Mortimer & Scott, 2003). By building a series of the IRF exchanges, the teacher actually shift the discourse practice from IRE to a more conversation-like genre and allowed students to build on their ideas or reasoning (Nassaji & Wells, 2000).

Facilitating a discussion-based discourse in classroom talk however, also requires an encouraging learning environment for mistakes. From our student interviews, we noted the importance of creating an encouraging learning environment so that students are not afraid of failed attempts and they will try to think of possibilities to answer the questions.

> I think I can learn better, especially when the teacher questions are not so easy to answer. Then I will collect all my knowledge from the previous lessons or from what I have read from the textbook. And especially when the teacher questions do not have exact answers… the answers are open. The teacher will discuss with you. Maybe the teacher don't have answer himself. So that you are not afraid that you will answer wrongly or correctly. So you just say what you think and the teacher will guide you the way along. And now the teacher are… friends, and he will rather be a person discussing with you rather than a person who is waiting to judge whether you are right or wrong. (Lily, year 10 student)

Thus, teachers can create a better learning environment by refraining from evaluations and encouraging students to "say what they think" and not having the fear of making mistakes.

Our interview with the teacher indicated that the teacher's beliefs and values were also a key influence on his instruction. When asked about his purpose of questioning, the teacher commented, "My questions guide students to clarify concepts, to think, to derive explanations and finally construct answers after making sense of the subject content." In addition, the teacher shared that he often "… ask another question to stimulate student's thinking and guide the student to another path of thinking" and "… ask other students' opinion or to comment on the answers. I will also ask more questions to guide students to check their thinking process." These beliefs and values to improve student's thinking appear to be significant influences in guiding the way he used questions and follow-up moves in class. Research studies in this area have indicated that teacher beliefs do play a significant role in influencing the implementation of teachers' classroom practices (Monteiro, Carrillo, & Aguaded, 2008; Roehrig & Kruse, 2005). When teachers are aware of the various aspects of their thinking, such as the beliefs and goals which underlie their classroom performance, they are able to have an improved understanding of their teaching style (Monteiro et al., 2008, p. 315).

Implications for Instructional Practice

Our work demonstrated that teacher prompts can serve various purposes and promote different cognitive processes among students. An implication of this is that when responding to students' answers, teachers have to pay close attention to the use of prompts. Being conscious and intentional in crafting appropriate responses to build on students' response, teachers can take students forward in their thinking and help them develop reflective thinking. As Chin (2006) posited, "if teachers are clear about the kind of cognitive processes that they want to elicit in their students, then they can craft questions that would stimulate such responses" (p.1341). The strategies proposed in this study reflected interaction patterns of IRF/IRFRF rather than the IRE chain. This implies that teachers need to withhold (early) judgment on students' responses and to focus on extending the science talk if they wish to promote more "constructivist-based" classroom questioning. Instead of judging a student's response as simply right or wrong, the teacher can provide non-explicit evaluations such as restatements or reformulations and apply prompts to encourage further participation. Morge (2005) asserted that teachers who want to move towards a constructivist teaching approach should avoid an authoritative style of managing the conclusion. Hence, teachers could redirect the evaluation process to other students which could encourage peer feedback. This does not mean that teachers should forgo assessment, rather it suggests that teachers should help students inquire and reflect deeper into their understandings before appropriating scientific knowledge. In this way, students are talking science to learn science (Lemke, 1990).

Another implication is that teachers should reduce the frequency of closed questions and introduce more open questions during classroom interactions. By asking open questions, teachers allow for more than one answer (Blosser, 1991) which is likely to encourage more student participation (Koufetta & Scaife, 2000) and to promote students' conceptual thinking (Chin, 2004). Furthermore, when teachers pose open-ended questions, they do not keep to one particular answer in mind, and are more likely to hear and find out more on what the students think (Walsh & Sattes, 2005). Such an instructional approach has also been associated with a high-level of constructivist teaching practice. Erdogan and Campbell (2008), for example, showed that teachers adopting a high-level constructivist teaching practice asked significantly greater number of open-ended questions and facilitated the students to construct knowledge based on the student explanations. These teachers emphasized the construction of knowledge in their instruction, questions, and interactions. Conversely, teachers adopting a low-level constructivist teaching practice asked mostly closed questions and directed the classroom interaction toward a predetermined answer. Little was done to encourage students to articulate their thoughts, but the teachers made long statements in an effort to clarify the learning that they believed was important in the lesson. These teachers focused their instruction, questions, and interactions on reproduction of knowledge.

A final implication from this study is that helping students become lifelong learners might not necessarily involve an extensive or elaborative school curriculum program for students (although it could be useful for schools to provide one such program). As shown in this study, teachers can make a difference with their classroom practices via talk scaffolding. By shifting teacher questioning from the IRE to a discussion-based IRF and applying prompts to probe students' reasoning or to encourage them to build on their answers, teachers can encourage students to develop deep thinking processes such as higher-order thinking and reflective thinking. Acquiring these cognitive skills are likely to help students be better equipped as a lifelong learners, enabling them to consciously take a self-directed approach to evaluate and modify their own ideas to advance their conceptual understanding in science (Chin & Brown, 2000).

Research Recommendations

The analytical framework developed by Chin (2006) has been fundamental in guiding the analysis of the teacher-student interactions and discourse moves. The components of the framework allowed for a systematic review of the interactional patterns, purposes, and cognitive processes behind the speakers' utterances. We have attempted to build on this framework by expanding on the question types associated with the follow-up moves. While the list given in this study has not been exhaustive, the findings have suggested that the interplay of these question types is implicit to the formation of various questioning strategies that promote deeper conceptual thinking among students. Hence, research could explore further into the question types and the roles and relationships in questioning strategies.

One pertinent issue emerging from this study is the role of student questions in facilitating their cognitive development. We noted several student questions in the lessons. Students' questions reflect their ability to monitor their own learning and to generate thoughtful ideas in the discourse and can act as a source for teachers to diagnose students' learning problems and thinking (Chin & Osborne, 2008). Van Zee et al. (2001) suggested that student questions that emerge during discussion provide evidence of their growing abilities to converse thoughtfully by explaining their ideas and asking questions. The existing framework employed in this study does not address teacher prompts in response to student questions. This can be an interesting area to take up for future research in classroom questioning.

Another area that was less explored in this study is the effect of wait time. This includes the time given to the students to think about the question or the time the teacher takes to think of a response (Rowe, 1986). Generally, a three- to five-second wait time allows students to think through the question more carefully and is likely to produce answers that are extensive and of higher quality (Tobin, 1987). However, researchers (e.g. Cotton, 1988; Roth, 1996) have alluded the need to consider the positive effects of longer wait time, especially when the teacher questions involved more complex mental operations. Certainly, future studies could look into issue of longer wait time with teacher prompts and whether it has a positive effect on students' cognitive development.

Limitations

A major limitation of this study is that the findings were based on one case study and derived from an interpretive analysis of data from the lessons of a class that the teacher participant taught. The questions and follow-up moves were unique features of this teacher and the discourse is contextualized to the particular class at the time of this study. Therefore, the findings are not generalizable across universal contexts. Another limitation is that in using Chin's (2006) analytical grid, the data from the lesson transcripts can be analyzed for ways in which the teacher's questioning approaches can facilitate students' thinking about the scientific concepts. But the process involves coding and categorizing the data according to the various aspects of the discourse illuminated in the grid which was at best inferential. Hence, as Chin (2006) pointed out, this entire process of coding and categorizing might not produce a high level of inter-coder reliability if the episodes were coded by another researcher. This problem is a fundamental weakness of the approach taken in this research.

A third limitation is that extensive teacher-student dialogues was not a common feature observed in the lessons. On many occasions, the teacher posed closed questions and provided explicit evaluation. The recitation or "IRE" exchange remained pervasive. Teachers in Singapore face constraints imposed by the prescribed syllabus and large class size (Chin, 2007). To guide students to acquire the basic content knowledge, recitation might be regarded as an efficient and effective approach to assess students' scientific knowledge. Teachers generally do not have ample curriculum time to allow for frequent discussions. Consequently, teachers may choose to adopt a "transmissive" approach of teaching rather than promoting inquisitiveness and active learning. Furthermore, the students are not forthcoming and seldom spoke up in class despite teacher encouragements and their uptakes or utterances in response to a teacher's feedback also tended to be brief and vague (Lyster & Ranta, 1997). As Chin (2006, p. 1343) explained, it is possible that Singapore students lack fluency in spoken English and may find it difficult to articulate and verbalize their thoughts in English although they may be actively engaged in conceptual thinking. Student disengagement from classroom questioning may have resulted from their fear of embarrassment from giving irrelevant or incorrect answers or the belief that the teacher only requires the same students to answer (Walsh & Sattes, 2005; Wragg & Brown, 2001).

Lastly, much of the data in this study were derived from the verbal exchanges between the teacher and a few students. The utterances and thinking processes were specific to the individual students who participated in the exchanges, but the assumption was that whatever applied to the individual respondent also applied to the rest of the students in the class. This is another major limitation since the “process of internalization does not simply involve direct transfer from social to personal planes and it is not possible to know for sure the extent to which the rest of the students were able to internalize and make sense of the concepts addressed” (Chin, 2006, p. 1342).

Conclusion

Promoting active learning and cognitive development for students is a task easier said than done. There are many challenges and constraints imposed by school factors and curriculum demands which could restrict teachers from delivering activities for these purposes. In looking at how teacher questioning could facilitate students’ deep thinking on scientific concepts, our work has demonstrated that a teacher’s responses to student answers in the IRF exchange appeared helpful in extending students’ conceptual understanding and promoting reflective thinking. The approach might involve the teacher’s avoidance of explicit evaluations and his/her use of appropriate acknowledgements and prompts in the follow-up move to encourage students to build on their contributions. In doing so, teachers could encourage students’ participation and stretch them mentally beyond factual recall. More importantly, such questioning approaches are likely to shift discourse practices from recitations to discussions, and foster a higher level of constructivist learning environment. As Costa and Kallick (2000, p. 34) stressed “careful, intentional, productive questioning is one of the most powerful tools a skillful teacher possess.” Certainly, teachers who put in efforts to improve classroom questioning have a greater success in enhancing the quality of thinking in classroom talk. Consider Dillon’s claim, “It makes no difference whether the question is higher- or lower-cognitive, whether it is simple or complex, whether it is fact or interpretation. What makes the difference is whether it is predetermined to be right, whether it is to be discussed or recited (Dillon 1994, p. 22).

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Appendix

Student Questionnaire

Please kindly fill in your particulars and then briefly write your reflections in the spaces provided. Thank you.

Name / Index No: ______________________________ (   ) Date: __________

Item	Your reflection(s)
Main thing(s) I learnt in this lesson	
A question I answered	
Something the teacher said that made me think	
A question I want to ask the teacher	
Any other comments	