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# Scaffolding scientific explanation in Chemistry through language-specific support

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Abstract

This paper draws on the work of teachers in Singapore in supporting Upper Secondary Chemistry students in the skills required for constructing scientific explanations. Specifically, the focus centres on examining scaffolding through mediating (Scott,1998) learning task and classroom talk to make explicit the demands required of explanations in Chemistry. Scaffolding is contextualized against a socioconstructivist research perspective (Applebee, 2002; Vygotsky,1978, 1986) as language-mediated activity and task-enabling support (Mitchell & Sharpe, 2005) for the construction of coherent, well-structured explanations. Teachers' design of pedagogic resources was examined specifically with regard to making explicit the links in causal relationships in scientific explanations. Teachers' classroom discourse was analyzed to highlight explicit moves in teacher–student interaction that support students in their interpreting and construction of content-specific explanations. Pedagogical implications and recommendations for classroom practice to support students' learning are discussed.

Keywords: Scientific explanation, Scaffolding, Language of Science, Classroom discourse, Scientific communication

# Scaffolding scientific explanation in Chemistry through language-specific support

## *Introduction*

There is a growing awareness of the significant role of language in meaning-making and learning Science in school (Lemke, 1990; Mortimer & Scott, 2000; Wellington & Osborne, 2001). According to Wellington and Osborne (2001), 'the greatest obstacle in learning science—and also the most important achievement—is to learn its language' (p. 3). Given the importance of language in the learning of Science, there is a need to understand how the subject-specific demands involve language for specific purposes in Science in order for learners to be 'socialized into the ways of knowing and practices of school science' (Driver et al, 1994, p. 11). This paper draws on school-based research in Singapore aimed at enabling Upper Secondary (Grades 9 and 11) students to meet the demands of explanations required in Chemistry through a focus on language-specific support. In Singapore, one of the goals in Science teaching and learning is to help students with the knowledge, understanding and application of scientific phenomena, facts, concepts and principles (MOE, 2012). Indeed, effective communication in Science where students can construct coherent and logical arguments to communicate and justify explanations (National Research Council, 2000) is a core skill that is emphasized not only in the local Science context but also beyond.

We begin with the background context and the research focus of the study before providing the theoretical underpinnings for key concepts and a select literature review which informed the study. We then describe the methodology and classroom practice before discussing pedagogical implications and recommendations.

## *Background context*

English has been the medium of instruction in the national school system in Singapore since 1987. Developing teachers' ability to communicate effectively in English is

acknowledged to be important for every teacher to achieve the desired student learning outcomes, communicate subject knowledge clearly and ensure students are able to draw on subject content knowledge to articulate their understanding, perspectives and reasoning.

The Ministry of Education (MOE), Singapore, launched the Whole School Approach to Effective Communication in English (WSA-EC) programme (ELIS, 2011) administered by the English Language Institute of Singapore (ELIS), as a strategic endeavor to support the development of teachers' and students' communication skills in all schools. As every academic subject has specific literacy demands, effective communication by subject teachers implies the skilful use of disciplinary-specific language to help students better understand, process and internalize subject content effectively in order to achieve targeted outcomes. Literacy in the subject refers to the ability to read, listen and view, to speak, write and represent so as to learn and acquire content knowledge in ways appropriate to a particular subject. This involves using language appropriately, meaningfully and precisely in the given subject area (Moje, 2008; Shanahan & Shanahan, 2012).

This study involved Upper Secondary Chemistry students in two classes (Secondary 3 [1] Express – 28 students and Secondary 5 [1]Normal (Academic) – 14 students) from a mainstream school in a public housing estate with students largely from an average to low socioeconomic background. The school on the WSA-EC programme is in collaboration with ELIS to raise the awareness of teachers of the literacy demands of subjects and to provide language-specific support to enhance students' learning of subject content.

[1] Students, depending on the Primary School Leaving Examination (PSLE) results and based on their ability to cope with their current learning pace and style, are placed on the standard four-year Express Course or the five- year Normal (Academic) Course leading to the Singapore-Cambridge 'O' Level certificate (Adapted from MOE, 2013, p.3).

### *Focus of study*

The overall objective of this study was to support students to meet the demands of scientific explanation in Chemistry through language-specific support. The interest centred on examining how teachers facilitated students' learning through the design and use of tasks and learning materials related to specific topics in the curriculum. In addition, how teachers used their classroom talk to reinforce the targeted learning tasks and how teachers can be supported to open up talk to enhance students' learning were also examined.

This study is guided by the following key research question:

How can teachers support students to meet the demands of scientific explanation in Chemistry?

Specifically, the study aimed to provide answers to the nature of this language-specific support and how it can be realized through concrete means in the Chemistry classroom. In particular, the attention focused on

1. how mediating the *task* was realised in pedagogic practice to support the construction of explanations,
2. how mediating the *talk* could open up classroom discourse to support students' learning, and sharpen accuracy and precision, and
3. what the pedagogical implications were for classroom practitioners.

### *Theoretical underpinnings*

This study draws on socioconstructivist perspectives (Applebee, 2002; Vygotsky, 1978, 1986) grounded in Vygotskyan (1978) belief in the internalization of social experiences in school mediated by tools such as language. Language is acknowledged to be important not only as the instrument of interactions (cultural tool) but also as an instrument of verbal thought (cognitive tool) (Vygotsky, 1986). How language functions as a key mediating tool

in learning activity and as a task-enabling support (Michell & Sharpe, 2005) to develop students' understanding and construct knowledge through instructional scaffolding (Wood, Bruner & Ross, 1976) is of interest in this study.

*Scaffolding as language-mediated activity*

Teacher-student discourse has been recognized to play a critical role in supporting the development of individual and joint intellectual understanding linked to student outcomes (Wells, 2000). Students' ideas about a topic or skill are elicited with the teacher adjusting her explanations based on students' responses and participation in discussion. This is of interest to this study where teachers' classroom talk, in particular, questioning strategies are examined with a view to deepening content learning through opening up the talk to engage more students in the co-construction of learning. This reinforces findings that at the early stages of learning, teacher modelling in concrete ways of what is required and engaging students in learning, particularly through active dialoguing in class (Hogan & Pressley, 1997; Scott, 1998), enhances students' learning.

Explicit scaffolding in the nature of modelling by the teacher before moving towards student participation (Applebee & Langer, 1983) encompasses think-aloud, talk-aloud and performance modelling (Hogan & Pressley, 1997). In think-aloud, the teacher verbalises the thought process used to solve a problem. Talk-aloud is where the process of learning as the individual goes through a task is verbalised. This is of particular relevance in this study where the teacher, in reinforcing the learning task, unpacks the critical aspects of the given task through explicit verbalising and talking through the task demands. Performance modelling involves teacher demonstration in carrying out the task without any verbal explanation.

*Scaffolding as task-enabling support*

Supporting students in the completion of learning tasks in class could also take the form of reception, transformation or production scaffolds (Mitchell & Sharpe, 2005).

Receptions scaffolds guide students in gathering and focussing on important information, for example, graphic organizers to aid students in organizing and recording what was read. Visual representations are recognized to 'reduce cognitive load, enhance representation of relationships among complex constructs' (O'Donnell, Dansereau & Hall, 2002, p. 72). Transformation scaffolds support students by setting up a structure on information, for example, task sheets to guide students to organise information logically. Production scaffolds prompt students to convey what they have learned effectively, for example, outlines for organizing information. These scaffolds could be used individually or integrated to support student learning as will be shown in this study.

How teacher support students in this study essentially draws on teachers acting upon the subject matter or content through what Scott (1998, p.76)) terms 'mediational means (focusing on language)' in ways which promote and sustain students' learning. Teachers are involved in 'supporting student meaning-making' (Scott, 1998, p.56) in how they mediate learning tasks set through specific teaching materials designed and used in class, and classroom talk to support students' learning.

*Scientific explanation*

Scientific explanation is acknowledged as central to Science education (Dagher, 1995; Treagust et al., 1992, 1996). Indeed, it is widely recognized that the purpose of Science is to explain phenomena (Stefani & Tsaparlis, 2009). The skill of explaining scientific concepts is 'critically important' to enable students 'to make sense of the world' (Horwood, 1988, p. 1). According to the MOE Science syllabus (2012), explanation is considered one of the essential features of scientific inquiry (p.7). Specifically, scientific explanation is involved in formulating hypothesis - the 'skill of making a general explanation for a related set of observations or events' (p.8) and inferring - the 'skill of interpreting and explaining observations, data or information gathered' (p.8).

Research literature distinguishes between ‘explanation’ and ‘description’ (Bateson, 1979; Horwood, 1988) in Science. Explanation is viewed as drawing connections between and among pieces of information (Bateson, 1979) where to explain a thing is ‘to map the thing onto a logical system of causality’ (p.81). Description, by contrast, is information which is isolated from any network of relatedness (p.81). Teachers tend to use the terms ‘explain’ and ‘describe’ loosely and interchangeably as evident in this study. This affects the message that Science students extract from Science teaching. Harwood (1988) stressed the need for Science teachers to be very clear about the distinction between description and explanation to enable students to be independent explainers and judges of explanations.

*Review of studies in the field*

Research literature that informed this study focused on studies that were related to teaching students’ scientific explanations and those that supported students’ learning in Science through scaffolding provided.

Studies on explanations in Science have revolved around teaching contexts in Australian and American settings. Seah, Clarke and Hart (2011) examined Australian Grade 7 Science students’ written language on “States of Matter” (Physical Science) with regard to scientific meanings related to the topic of expansion and the challenges involved. Attention to lexicogrammatical resources based on specific scientific phenomena proved invaluable in helping students with precision in language use. The study emphasized the need for discussion and explicit unpacking of the task requirements for students, clarity in explanation of specific aspects through appropriate grammar and discourse features of the targeted genre, and scaffolding the writing process through a staged process.

Dagher and Cossman’s(1992) work on the teaching of explanations in Physical and Life Sciences at Grades 7 - 8 in the US focused on a range of teachers’ oral explanation types. Classroom recordings and transcripts were examined for characteristic features that

categorized each type. Teachers differed in explanation types used for specific purposes. Explanations that featured most frequently were the 'practical (how-to)' (Dagher & Cossman,1992) explanations as opposed to 'theoretical' ones. These comprised genetic (relate to antecendent sequence of events), mechanical (specify causal relationships that are generally physical), practical (detail how to perform physical or mental operations), and analogical (make familiar situation similar to unfamiliar phenomenon) (p.364-365). Although the classification may come across as systematic, it remains 'in a sense arbitrary' (p.371) and more research needs to be carried out to validate teachers' and students' perspectives on the explanation types.

Studies on scaffolding students' learning featured predominantly work with younger learners at the elementary level. Yang and Wang's (2013) study involving two Grade 4 classes showed that students who were provided strategies integrating descriptive explanation (describing processes and structures of phenomena), concept mapping and interpretive explanation (drawing on claim, evidence and reasoning) were able to construct scientific explanations with evidence of logical reasoning compared to the control group. There is room for more work on sequenced tasks with a greater number of students at higher levels and for measuring students' progress in learning scientific explanation.

Kamaliah et al (2011) examined the impact of scaffolding structures on Grade 6 students in answering open-ended Science questions. Structural frameworks such as procedural steps to craft answers or explicit questions guided students in their thinking process. The support structures enabled students to identify relevant Science concepts for questions assigned and aimed to help them achieve completeness and accuracy in answers.

Overall, there remains a dearth of investigations with documented research in educational contexts which involves the explicit teaching and learning of explanations with a focus on supporting teenage students through concrete scaffolding and support strategies

sustained over a period of time that mediate the process of learning. A number of the available studies on scaffolding in Science involved primarily relatively younger participants. This study, in supporting Secondary students within a specific pedagogic context in Chemistry to fulfil targeted curricular goals, fills a gap particularly in the current local research and pedagogic contexts in this region.

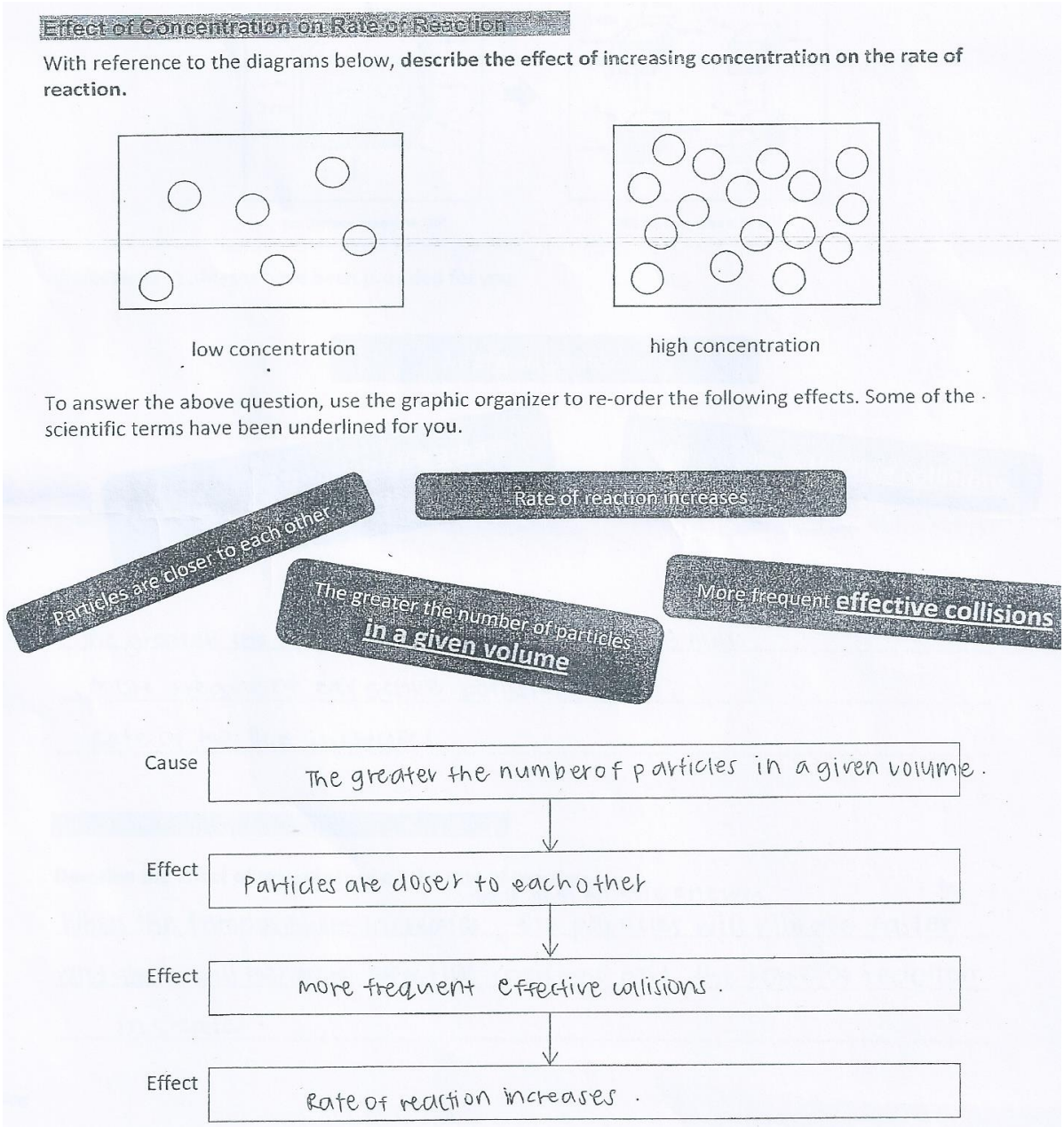
## *Methodology*

This study adopted an interpretive approach to qualitative data analysis. This is relevant to a study that approached the use of language as contingent on its use at a particular moment in time and space in the flow of a social situation (Bloome & Clark, 2006), particularly in the context of the classroom discourse, where relevant, and in specific classroom contexts, given the demands of tasks set for students. This study was sited in the naturally occurring setting of a Secondary science classroom. The naturalistic nature of the data provided the groundedness for revealing the authenticity and complexity of discourse and the nature of tasks as they unfolded (Miles & Huberman, 1994). Specifically, for the purpose of this paper, the data presented were confined to the work related to the topics of rate of reactions and ionic and covalent compounds.

Data sources drawn for this study included resources from both teachers and students. These comprised teachers' instructional materials, students' written work, video recordings of lessons, transcripts of recorded lessons and students' feedback from survey forms administered. Teachers' and students' input (represented by T for Teacher, and S1, S2 etc. for Students who were numbered) were unedited and recorded verbatim in this paper. Italicised extracts of texts were the authors' for emphasis. The study adhered to research ethics guidelines of the Ministry of Education.

*Mediating the task*

Mediating the task in this study focused on the design of learning tasks and teaching materials used by the teachers in class. The instructional scaffolds built into the task sheets operated on different levels and reinforced each other in the way they were integrated for use in the class. Reception scaffolds (Mitchell & Sharpe, 2005) were realised in the design of the task sheet to focus and draw attention to the given context. This could include visual representations in the task sheet and cut-outs of segments of texts. In this paper, we focus on the graphic organizer which served as a visual aid to help students think through, identify, select and organize key information required. The structure of the graphic organiser was in itself a representation of transformation scaffolds (Mitchell & Sharpe, 2005) to support students by imposing structure on the content. This was aimed at enabling students to focus on and organize the key information required in order to structure the flow of information in explanations required. The graphic organiser also served as a template in prompting students to organize the given information in order to generate the targeted explanation and can also be seen as a 'production scaffold' (Mitchell & Sharpe, 2005) at this stage of the lesson. At the same time, the 'languaging' required through the use of the appropriate language to convey the critical aspects of the scientific process was foregrounded by drawing students' attention to the underlined phrases. In the topic of speed of reaction, Figure 1 captures the representation of the various scaffolds in one sample task.



Effect of Concentration on Rate of Reaction

With reference to the diagrams below, **describe the effect of increasing concentration on the rate of reaction.**

low concentration

high concentration

To answer the above question, use the graphic organizer to re-order the following effects. Some of the scientific terms have been underlined for you.

Particles are closer to each other

Rate of reaction increases

The greater the number of particles in a given volume

More frequent effective collisions

Cause: The greater the number of particles in a given volume.

Effect: Particles are closer to each other

Effect: more frequent effective collisions.

Effect: Rate of reaction increases.

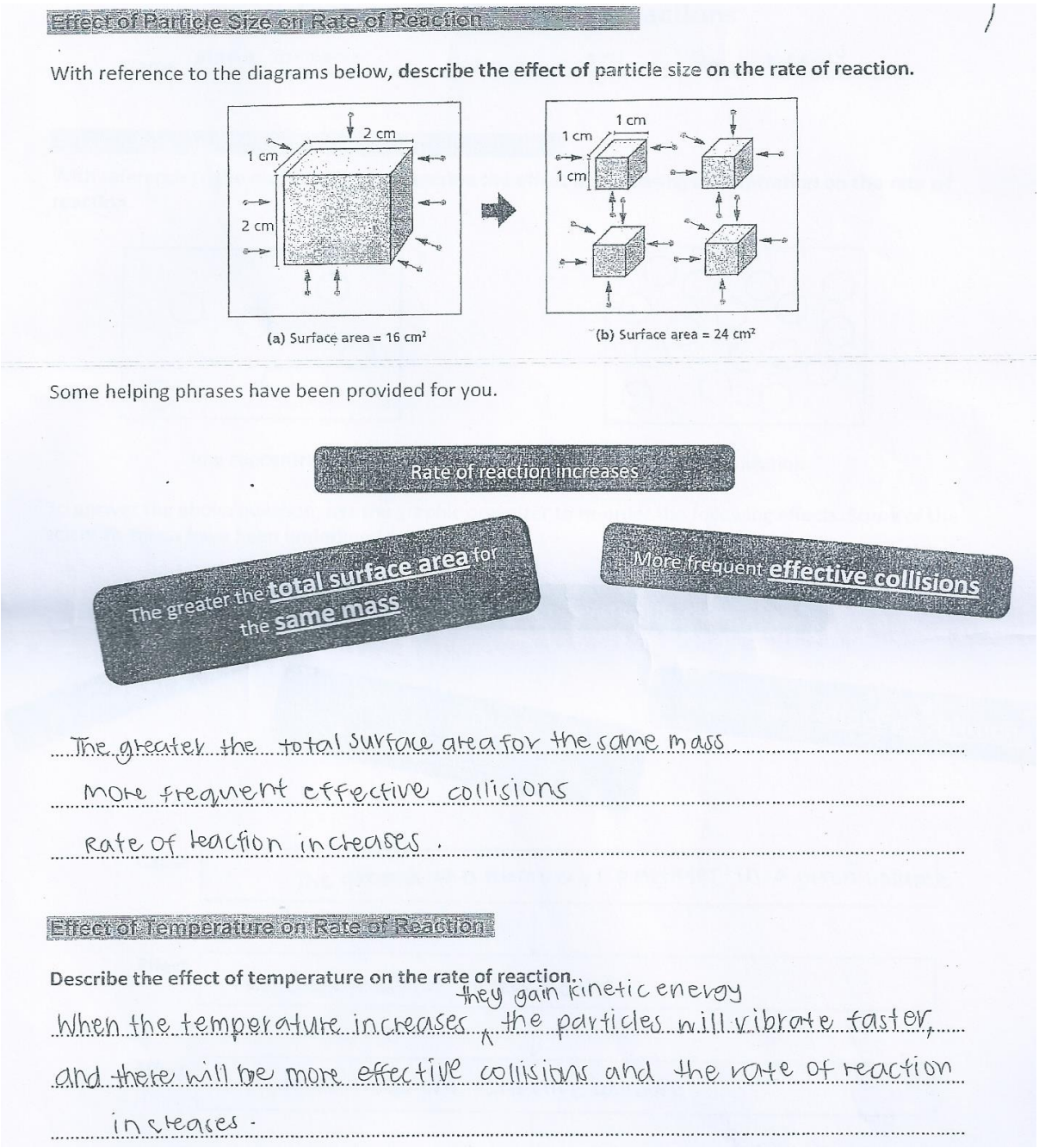
Figure 1. Task sheet with graphic organizer
Effect of concentration on rate of reaction

The visual in the task sheet with two boxes showing contrasting representations of low and high concentration provided the initiating stimulus for contextualizing the task. Students had to account for the effect of concentration (low, high) on the rate of reaction. In addition, students were provided with cut-outs of the essential content, supported by the language required, to explain the underlying cause and series of effects. Key phrases that were critical to the scientific phenomenon were underlined to draw students' attention ('in a given volume', 'effective collisions'. The flow chart represented in the graphic organizer served as a visual aid to guide students in sequencing the cause-effect relationship through the series of boxes linked to each other by downward arrows in a linear fashion.

It was noted that the use of the command word 'Describe' as the instructional prompt in the task to unpack the cause-effect relationships as in the effects of increasing concentration (Figure 1), particle size (Figure 2) and temperature (Figure 2) on the rate of reaction is inaccurate. This would have been better replaced with the word 'Explain' in alignment with the perspective of explanation involving logical relations of causality (Bateson, 1979) as earlier discussed.

Figure 2 realized the reception scaffold (Mitchell & Sharpe, 2005) through the visual aid of the initiating stimulus to contextualize the task with the two boxes showing contrasting representations of larger and smaller particle size. This served to focus students' attention on the specific variables in this new context. Unlike the earlier task, the transformation scaffold (Mitchell & Sharpe, 2005) for delineating the structure through a graphic organizer with the series of boxes linked by arrows is now absent. The releasing of this aspect of the scaffold was intentional as the aim was to have students work with the cut-outs of information provided on their own. Students had to think through the logical relations at play and generate the sequence of stages involved with the given content. The key information students required remained highlighted through the underlining of the essential key phrases for the

given context: ‘the total surface area’ for ‘the same mass’ and ‘effective collisions’. The blank spaces provided were for students to construct their explanations in continuous prose for both the variables of particle size and temperature. This task did away with any explicit production scaffold (Mitchell & Sharpe, 2005) of a template or graphic outline for students to structure their answers. The gradual release of scaffolds in the task design was deliberate to help students work towards internalising the content required to explain the processes involved and to express this understanding independently on their own.



Effect of Particle Size on Rate of Reaction

With reference to the diagrams below, **describe the effect of particle size on the rate of reaction.**



(a) Surface area = 16 cm²

(b) Surface area = 24 cm²

Some helping phrases have been provided for you.

Rate of reaction increases

The greater the **total surface area** for the **same mass**

More frequent **effective collisions**

The greater the total surface area for the same mass
more frequent effective collisions
Rate of reaction increases.

Effect of Temperature on Rate of Reaction

**Describe the effect of temperature on the rate of reaction.**

When the temperature increases they gain kinetic energy the particles will vibrate faster, and there will be more effective collisions and the rate of reaction increases.

Figure 2. Task sheet with graphic organizer
Effect of particle size and temperature on rate of reaction

It is noted that, in this lesson, the use of specific language features, namely connectors and verb forms that express cause-effect relations, were not made explicit in the tasks set. Attention to these for example, connectors or linking words that signal cause and effect such as ‘thus’, ‘hence’ and verb phrase ‘*results’/’resulting in’* or ‘leads to’/’leading to’ to

demonstrate relationship between factors and consequences, would tighten the coherence and make explicit the targeted causal relationships in students' explanations. Teachers were encouraged to incorporate these into their teaching which were followed up in subsequent lessons. It was noted, however, that students in this lesson were able to use the appropriate connectors 'When', 'and' (Figure 2) in the last section on explaining the effect of temperature with the resulting consequences.

## *Mediating the talk*

In this study, explicit language-specific support with regard to classroom discourse was examined through mediating the classroom talk for specific purposes. We examine mediating the talk to reinforce the use of the given learning task before turning our attention to mediating the talk to open up classroom talk to support students' learning, and for sharpening accuracy and precision in explanations.

### *Mediating the talk to reinforce learning task*

Instructional resources, on their own, may not be sufficient in enabling students to fully understand what is involved in moving from explaining one stage of the process to another. There is a need for reinforcing students' learning through the task with verbalizing explicitly what students need to be made aware of particularly at the early stages of learning. Teachers' classroom discourse is critical in guiding students to be aware of the structure or organization of explanatory texts with the appropriate language required based on learning tasks used in class.

In the lesson on speed of reaction, the teacher supported her use of the graphic organizer for the construction of the explanation with explicit teacher talk that focused on the key aspects of what was required in a systematic, step-by step manner. The teacher sharpened

students' focus on the given context of the task, that is, resulting effects on the rate of reaction given the increase in volume of particles from low to high concentration:

> Alright? So now back to the diagram. If we say that, from low to high concentration right, the number of particles have increased in the same volume. Then what do you expect will happen after that? Ok?

The teacher drew students' attention to the number of blanks as a means of targeted attention to the scope of the demands of the task:

> Now you look at your…you look at the *graphic organiser* that's given to you, there are altogether four blanks there. Alright?

The teacher made explicit the purpose or rationale of the use of the visual resource and contextualised the significance for doing this in the context of formal assessment:

> Now, in the exams they will ask you to describe the effect of increasing concentration on the rate of the reaction. So this graphic organiser has been given to you for you to *arrange* the *sequence of events* to *explain the effects* of increasing concentration on the rate of reaction.

The teacher highlighted to students the content-specific language support provided that has been made explicit ('those words that have been highlighted and underlined') and explained the rationale for the relevant concept vocabulary and specific scientific terms 'that are important to use when you are describing or explaining something'. The teacher highlighted to students the distinctive nature of the content-specific terminology which 'you do not use in your usual day language' but are important 'when we talk scientifically about concepts':

> Now, there are four helping phrases there given to you and then if you notice, right, those words that have been highlighted and underlined, these are the *scientific terms* that are important to use when you are describing or explaining something. Now scientific terms are things like you do not use in your usual day language. But when we talk scientifically about concepts, it is important that you start using some of these words. Ok? So when you study, you need to pay attention to the usage of these words.

The teacher further drew students' attention to the cause-effect relationship involved and made explicit what was expected of the 'cause' segment in the specific context of the explanation:

T: So now if we look at your graphic organiser, you will know notice that there is a *cause and effect*. Ok, let me explain. The *cause*…when we talk about the cause, I want you to tell me when I increase the concentration, what will that immediately cause.
S2: Particles are closer to each other.

The teacher, through a series of questions that built on students' responses, focused students' attention on the effects following each stage of the process: 'Before the particles get closer together', 'And then after that', 'after the particles are closer together', and elicited students' responses on the resulting consequences: 'what is the first immediate thing that happens', 'what is the effect of having greater number of particles', 'what will happen':

T: Err...particles are closer to each other. Ok, look at the diagram ah. Before the particles get closer together, what is the first immediate thing that happens?
S3: Greater number.
T: Yea, there is actually a greater number of your particles right? Within the same volume. And then after that, what is the effect of having greater number of particles?
S3: Rate of reaction… Eh no, particles are closer to each other.
T: So, this is our no.1 agree? This is actually the cause. After you have a greater number of particles, you told me that the particles are now closer to each other. So that is no. 2 right?
T: Ok, so you fill in accordingly. So that's no.2. after the particles are closer together, what will happen?
S: Rate of reaction increases.

The teacher highlighted what was central to the understanding of the 'rate of reaction' in eliciting the end-stage consequence: 'final effect' and reiterated the need to 'identify the immediate cause' before 'the subsequent effects':

T: Very good. Actually more frequent collisions will take place. Then after that you will have the final effect which is your rate of reaction actually takes place.
T: Ok so you identify the immediate cause then after that the subsequent effects.

The teacher consolidated students' understanding by reinforcing, at the end of this stretch of discourse, the purpose for going through the staged breaking down of the process into a series of steps to explain the stages involved. The distinction between merely stating the final effect and explaining each step of the process, including the 'intermediate effects' involved as one goes 'through all the different steps', was made explicit:

> Ok why is it that we have to go through this process when we talk about describing? When the question asks for describing, you cannot straight away jump to the final effect. If you jump to the final effect, that is just stating. If they say, state the effect of increasing speed of reaction. Then yes, you can give me the final effect. But if they say *describe*, you actually have to *go through all the different steps*. Ok, like step 1, step 2, step 3. Then you'll come to the final effect. Understand? Ok? So whenever the question ask for a describe, never just go straight to the final effect. You have to list down the *intermediate effects* before you come to the final one.

It would have been more accurate had the teacher used 'explain' over 'describe' as discussed earlier to reinforce the need for making explicit the causal relationships involved. Knowledge of Science involves understanding the relationships among ideas and concepts. When students organize their knowledge around concepts, they remember them better. Talking about the procedural steps involved helps students to build connections among the relevant skills and concepts.

*Mediating the talk to open up talk for learning*

Mediating to open up classroom talk to enhance students' learning focused on supporting the teacher with specific 'talk moves' (Chapin, O'Connor & Anderson, 2013) that is, 'strategic ways of asking questions and inviting participation in classroom conversations' (Chapin, O'Connor & Anderson, 2013, p.11) . This was with the aim of 'making progress toward achieving instructional goal of supporting' content learning (p.11) through facilitating productive academic discussion between teacher and students in class. The focus was on expanding the teacher's repertoire in questioning strategies to open up talk for learning. In examining teacher's discourse in class, we identified the talk moves displayed by the teacher

for realizing specific purposes. Different moves are recognized to serve different functions. Potential talk moves and frames for prompting students' response (adapted from Michaels & O'Connor, 2012; Zwiers & Crawford, 2011) aim to provide opportunities for opening up classroom talk to engage students actively in the process of learning through incorporating more students' voices to expand the dialogic space of learning.

The following extracts illustrate segments of the teacher's classroom talk (Utterance) identified for what the teacher expressed in class (Teacher's Talk Moves) and which are recast to sharpen the focus and to enhance students' learning through recommended strategic moves (Possible Talk Moves & Frames for prompting).

In the lesson on ionic compounds, the teacher's 'Some more' in seeking elaboration can be made more explicit through eliciting other students' views on what a student, Jeanie, had offered on 'wires'. Students can also be guided to build on their peers' contributions and further prompted for their reasoning:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | Wires. Some more? A type of energy. Ok. What exactly is it? Got positive and negative charge, according to Jeanie. | **Seek elaboration**<br>*Some more?* | **Elicit students' views on peers**<br>What do you think about what Jeanie has said?<br><br>**Guide students to build on peers' contribution**<br>Who can add on to what Jeanie has just shared?<br><br>**Probe for reasoning or evidence**<br>Why do you think she said that?<br>How did she come up with that answer?<br>Who can give further evidence to support what Jeanie said? |

In attempting to elicit the definition of a phenomenon, the teacher's pointed question 'So what exactly is electricity?' may remain challenging to students. They may benefit from being asked to clarify what they understand by the term and to have what was said revoiced for verification:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | So it involves charges. So what exactly is electricity? Charge? Ok, electricity is the movement of charges. Alright? You know it as when electrons move around the circuit, it | **Elicit definition**<br>*So what exactly is electricity?*<br><br>**Provide information**<br>*Ok, electricity is the movement of charges.* | **Seek clarification**<br>What do you mean by electricity?<br>Can you be more specific?<br><br>**Revoice for verification**<br>Let me see whether I |

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| | creates a current. | *Alright? You know it as when electrons move around the circuit, it creates a current.* | understand you correctly. Are you telling us that movement of charges is electricity?<br><br>**Elicit students' views on other students' ideas**<br>What do you think about what X has just said?<br>Do you agree or disagree ?<br>Can you explain why?<br><br>**Probe for reasoning or evidence**<br>How do you know that?<br>What's your evidence for saying current results when electrons move around the circuit? |

Attempts can further be made to encourage students to respond to their peers' ideas and to probe for reasoning or evidence to support ideas put forth.

The teacher, in the following, in seeking the students' reasoning on 'Why is it that ionic compounds can conduct electricity?' can be further guided to encourage students to challenge assumptions made and to prompt for reasoning or evidence to deepen students' understanding:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | Now, electrons carry a charge. But electrons are not the only particles that carry a charge. Now you need to remember this. Electricity is the movement of charges. Alright, now why is it that ionic compounds can conduct electricity? | **Seek reasoning**<br>*Why is it that ionic compounds can conduct electricity?* | **Challenge statement or assumption**<br>Are you sure that ionic compounds can conduct electricity?<br>Is it always the case?<br>Are there other particles besides electrons that carry a charge?<br>What do you think?<br><br>**Probe for reasoning or** |

| | | | |
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| | | | **evidence**<br>How can you support the idea that ionic compounds conduct electricity?<br>What is your evidence for saying that? |

Likewise, in seeking explanation of a process 'Where does the charge come from?', there is a place for pressing for reasoning or evidence in order to establish understanding of the targeted phenomenon and to enable students to draw links to what was learned earlier about molten and aqueous states:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | Electricity is the movement of charges. Alright, now why is it that ionic compounds can conduct electricity? Why? | | |
| S14 | <inaudible> | | |
| T | Because got a lot of charge. Where does the charge come from? The bonding. The bonding creates a lot of charge. Because they lose, then they gain electron so there's a lot of charge. Ok you know that ionic compounds must have charges. Alright? | **Seek reasoning**<br>*Where does the charge come from?* | **Probe for reasoning or evidence**<br>How does that link to what we found out about molten and aqueous states earlier? |
| | | **Provide information**<br>*The bonding. The bonding creates a lot of charge. Because they lose, then they gain electron so there's a lot of charge. Ok you know that ionic compounds must have charges.* | **Ask student to restate contribution**<br>Can you put in your own words what you understand from what has been said about bonding and charges?<br><br>**Guide students to build on contribution**<br>How does this link to what you know about ionic compounds? |

Instead of providing information on the source of the charge, the teacher could further encourage students to restate what was provided in order to check for students'

understanding and guide students to build on information shared by drawing links to what they may know. This is to determine if students are able to make the necessary connections to relevant key information to explain the targeted phenomenon.

In seeking reasoning: 'What does that mean*?'* in relation to electrostatic forces, free moving ions and potential difference, there is room for a restatement of what was just said to confirm understanding and for further probing for reasoning or evidence:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | ….So in molten and aqueous state, the strong electrostatic forces between ions are broken down, the free moving ions carry the electric current when a potential difference is applied. | | |
| | | | **Ask student to restate contribution**<br>What do you think about what was just said?<br>Can you go over again what was mentioned? |
| T | What does that mean? Sorry, copy the second one first. Later on I'll tell you the first one again. Ok so in molten and aqueous state, the strong electrostatic forces between ions are broken down, the free moving ions carry the electric current when a potential difference is applied. Understand? So that's why they can conduct electricity. Understand? Got response or not? Little bit of response please. Yes or no. | **Seek reasoning**<br>*What does that mean?*<br><br>**Seek reasoning**<br>*Understand? So that's why they can conduct electricity. Understand? Got response or not? Little bit of response please. Yes or no. Yes yea.* | **Prompt for reasoning or evidence**<br>Are you convinced over the effects of electrostatic forces breaking down and what happens to free moving ions? Why do you think that?<br><br>**Get students to summarize or consolidate**<br>What have we discussed so far?<br>What have we learnt about the conduct of electricity through our discussion?<br>N, could you recap the key points that we can take away from this discussion? |

Where attempting to verify students' understanding is concerned as in 'Understand?', particularly after an extended stretch of discourse, students would benefit from concrete attempts to elicit and summarize or consolidate their understanding of concepts discussed.

In the next extract, when eliciting understanding of what can conduct electricity, students could be challenged to offer a counter-argument and be prompted for the appropriate reasoning in the given context:

| Speaker | Utterance | Teacher's Talk Moves | Possible Talk Moves & Frames for prompting |
|---|---|---|---|
| T | Nigel, explain to me what's happening. Why is it that it can conduct electricity? Don't read up the…I also know. What does this mean? Do you think it can conduct electricity in the solid state? No ah? Why cannot? Too hard? So metals cannot conduct electricity in the solid state also because too hard? | **Seek reasoning**<br>*N, explain to me what's happening. Why is it that it can conduct electricity? Do you think it can conduct electricity in the solid state? No ah? Why cannot? Too high? So metals cannot conduct electricity in the solid state also because too high?* | **Challenge statement or assumption**<br>What can conduct electricity in the solid state?<br>Do metals always work this way?<br>I'm not sure whether I'm convinced that metals cannot conduct electricity as they are too high.<br>What do you think?<br>Can you think of counter-examples?<br><br>**Prompt for reasoning or evidence**<br>Have you ever come across cases like that?<br>How can you support that? |

How the teacher opens up the dialogic space in the classroom to make draw on more students' voices in order for students to co-construct knowledge and be actively involved in the meaning-making process together with the teacher and their peers is valuable. Teachers' questioning and response moves can function as a scaffold to extend and clarify students'

ideas, to draw out the reasoning behind them and to connect them to the ideas of others. As Nystrand (1997) has argued,

> 'How students think – indeed the extent to which they really need to think in school – and consequently what they can learn depend a lot on how their teachers respond to their students' responses.' (p. 29)

how the teacher uses strategic questioning to guide and probe more deeply students' thinking and unpack their reasoning of concepts or issues discussed can impact students' learning. When the teacher builds on the students' response and positions the student for further clarification, elaboration, justification and even challenge, the teacher stimulates deeper thinking in the student about what was discussed. The teacher's moves in being responsive to the students' answer encourage elaboration, justification and counter-perspectives. This extends the scope and depth of the discussion in class. Where there is no prompting for underlying reasons and evidence or encouraging and guiding students to respond to and engage with ideas put forth, the opportunity for sustained interaction and deep learning is lost.

*Mediating the talk for accuracy and precision*

Teacher's drawing students' attention to the use of accurate and precise subject-specific terminology is invaluable for supporting students to make explicit the explanation required. There is a difference in particles 'expanding' as opposed to particles 'moving faster' and being 'further apart from each other' when temperature increases as the teacher pointed out in the following:

> So there was a comment just now, that when we increase the temperature, your particles *expand*. Now don't be…ok you all very <inaudible> Ok, ok very good.
> Ok listen, it is not accurate for us to say that when temperature increase, your particles expand. The object will expand when we increase temperature. But the individual particles inside it does not expand. You see the object expand because the *particles can move further*

> *apart*. That's why they expand. Understand? So please do not tell me that your particles expand when your temperature increase. Your particles are *moving faster*, they can be further apart from each other. Therefore the actual object expand. Alright? But that was a good point that was brought up.

There is a place in classroom teaching for identifying students' misuse of scientific language. This can be a powerful diagnostic tool for uncovering students' misconceptions in specific areas of content. Inaccurate use of language and inappropriate terminology could unnecessarily add on redundant information, omit or overlook critical information and/or completely reverse or transform the expression of key content specifics required in explanations. The ability to use precise, accurate and concise use of language in explanations is a skill all students need to develop.

*Students' feedback*

Feedback from students through the survey administered on the specific support scaffolds in the tasks used in class provided insights into what they considered helpful or otherwise. 92% agreed that the graphic organizer and breaking the text down into segments or cut-outs with the necessary information and language required to explain the targeted processes were useful. Illustrative responses from students that were representative of the gains in specific areas were noted and represented as follows. Students' responses indicated the support scaffolds helped them in specific ways. These included functioning as an aid to enhance overall content learning ('useful as we know more about the topic'), to remember key terminology and content vocabulary ('useful as i can remember the key words', 'allows me to fully understand the different terms', 'helps us understand the words better and using them in explanations'), to ensure clarity ('and you get a better clarity of explanation by breaking down the text'), to internalize, process and even transfer understanding of content to another form ('It was very strongly useful. I find it a good use for notes. And it is also

very easy to understand as it is broken down. :)', to aid in targeted content recall and reinforcement ('useful because it is easier to remember than reading and reading everything all over again), and even to motivate students in content learning ('it made the class more interesting') as specific ways they have gained from their use.

For the smaller proportion of students who disagreed over the value of the scaffolds built into the tasks, they appeared to have difficulty in understanding even what was required of them and how to apply this understanding in specific contexts. These students obviously faced challenges beyond the demands of scientific explanations given their weak command of the language. Teachers' making explicit their instructions for given tasks right at the outset and modeling what was required of students with regular checking-in to monitor students' understanding at critical stages of the lesson could ensure such students are kept on task and are clear as to what is required.

Students' feedback on the teacher's talk moves was beyond the scope of this paper at this point in time although further work in this ongoing study is underway for teachers to study the impact of the talk moves on their students' learning.

*Students' written explanations*

Students' work was examined after successive weeks in a term of teacher-guided instruction with the support measures for explanations. The task required making explicit the difference in electrical conductivity between the two compounds:

Ionic compounds conduct electricity in molten and aqueous state while covalent compounds do not conduct electricity in any state. Explain the difference in electrical conductivity between a covalent compound and an ionic compound.

The expectation was for students to detail the specifics of the contrast in the given context and to articulate clearly the underlying principles and reasoning involved.

The following students' answers exemplified a representative sample with attention given to highlighting the contrasting features with the use of relevant language features,

namely, connectors showing causal and contrasting relationships. Attempts at making explicit the reasoning behind the phenomenon varied in terms of specificity:

| **Sample students' answer** | **Features** |
|---|---|
| Student A | |
| An ionic compound can conduct electricity in molten and aqueous state *because* they have free moving ions to carry electricity when a potential difference is applied. *On the other hand*, a covalent compound does not have free moving ions to carry electricity. | Contrast in how the two compounds differ<br><br>Use of connectors 'because' to convey the causal links and 'on the other hand' to express the contrast<br><br>Reasoning and outcome present. Links to underlying principle (whether strong electrostatic forces are broken) could be made explicit |
| Student B | |
| In aqueous or molten state, potential difference is applied, *hence* the electrostatic forces of attraction in ionic compounds will be broken down, *thus*, there will be free moving ions that carry electric current.<br><br>*However* in covalent compound, there are no free moving ions to carry the electric current. *Therefore*, ionic compounds is able to conduct electricity in molten and aqueous state *while* covalent compounds cannot. | Contrast in how the two compounds differ<br><br>Use of connectors 'hence', 'thus', 'therefore' to convey the causal links and 'however', 'while' to express the contrast<br><br>Reasoning and outcome present. How concepts are linked can be worked on for accuracy |
| Student C | |
| Ionic compounds have free moving ions in the molten and aqueous state and *when* a potential difference is applied the free-moving ions can carry the electrical current. *However*, covalent compounds have no free-moving ions to carry the electric current *when* a potential difference is applied. | Contrast in how the two compounds differ<br><br>Use of connectors 'when' to convey the causal links and 'however' to express the contrast<br><br>Reasoning and outcome present. Links to underlying principle could be made explicit |

By contrast, students who were not exposed to the support measures and explicit scaffolding indicated a lack of awareness of the need to show the differences between the two compounds. There were also inaccuracies in the use of key terminology required to ensure clarity and accuracy in the explanations as evident in the following:

| **Sample students' answer** | **Features** |
|---|---|
| Student D | |
| Covalent compound does not have electrical charged ions which can conduct electricity. | Incomplete- No contrast indicated between the compounds<br><br>Inaccurate use of terminology 'electrical charged' to explain phenomenon |
| Student E | Incomplete- No contrast indicated between the compounds |
| A covalent compound does not have any free mobile ions to carry the current. | Inaccurate use of terminology 'free mobile ions' to explain phenomenon |
| Student F | |
| Ionic compound has free flowing electrons in molten and aqueous state while covalent compound does not have free flowing electrons in gaseous states. | Use of connector 'while' to express the contrast<br><br>Inaccurate use of terminology to explain reasoning: 'electrons' (over 'ions'), 'free flowing' (over 'free moving')<br><br>Inaccuracies in conceptual understanding: 'gaseous states' |

*Pedagogical implications*

This study has shown that the design and use of instructional materials in the form of task sheets, teaching materials, learning resources requires careful consideration by teachers if these are intended as explicit forms of learning support for students. The nature and purpose of the visual resources and graphic representations to meet specific purposes in particular learning contexts are critical aspects of pedagogic support any Science teacher would do well to take into account. The support scaffolds could aim to focus and draw

attention, scaffold thinking, and/or identify, select and organize information. The extent to which these resources could be further amplified with the relevant language support in the form of accompanying content-specific terminology required must also be considered. In meditating the task, there is also a place for the interplay of different types of scaffolding at various levels to meet targeted outcome(s). How the instructional scaffolds built into the task sheets operate on different levels to varying degrees and how they reinforce each other in the way they are integrated for use in the class are critical considerations for the teacher.

Teachers also need to consider how and when these learning resources with in-built support mechanisms are intended for use the classroom - for example, complementary teaching resources to guide students in the initial stages of learning, supplementary resources to reinforce students' learning in the process of unpacking a complex topic/concept or enrichment resources to further extend students' learning. These would influence the nature and extent of the support scaffolds provided and how they are used to enhance students' learning.

The study has also illustrated the strategic use of scaffolding with supportive structures in place through a staged, step-by-step process that is systematic and purposeful. This includes the support realized through visual supports that aid in contextualizing the task to graphic organizers with the appropriate language-support that set up an explicit structure to guide students' thinking and scaffold targeted responses. At the same time, there is a need for the gradual release of scaffolds, if, indeed, these are meant to be temporary means of support, at the appropriate place in instruction, in order for students to internalize and process the content specifics required for the construction of the explanation.

The study has also demonstrated the role of classroom discourse in subject teaching to develop students' ability to reason and communicate that reasoning scientifically through reinforcing the learning tasks adopted and resources used. For talk to be effective for

learning, mediating the talk to align the visual with the textual in the given learning tasks and resources for purposeful meaning-making is essential. Teachers could give attention to whether their talk enables students to make sense of the visual resource (such as graphic organizer, template) to structure their thinking along specific lines, organize the content and/or express the logical relations in the given context. Teachers may also need to consider how their talk is supportive in making explicit the procedural steps involved to reinforce links or connections made across stages in the process of unpacking the concepts.

Teachers could work towards using classroom talk to expand the dialogic space in class and to engage students more actively in co-constructing knowledge together with each other and/or the teacher. Teachers need to strategize to engage students in these communicative practices and to make explicit the language-specific demands that these practices entail at the appropriate segments in their lessons. Professional development of subject teachers could incorporate strategies in the way ELIS is presently working with schools through a suite of courses offered to broaden teachers' repertoire of questioning strategies and to incorporate relevant talk moves targeted for different purposes. In addition to talk moves for promoting effective talk, attention also needs to be given to how students can be supported through relevant and appropriate prompts for responding. Supporting teachers to work towards sustained interactions in extended dialogue through encouraging elaborated responses from students as they clarify, affirm, challenge and synthesize each other's responses would go some way in the construction of well-formed explanations. Subject teachers need to be encouraged to open up talk and interaction in class for deepening understanding of how teachers can engage students in unpacking the specifics required to realize scientific explanation, to ensure precision and accuracy in the language used, and to stimulate and sustain academically productive talk in the classroom. Ultimately, the MOE aims to develop a repository of lesson recordings with annotations of how skillful

teachers strategize and adopt strategic talk moves in fluid and productive ways to further enhance students' understanding of the content they are learning.

*Conclusion*

This study contributes to a growing interest in the field in examining how students can be supported through explicit language-specific support in scientific explanations. What teachers design for their learning tasks and instructional resources and how these are used in class can be harnessed effectively to impact teaching and learning. Improving communication in class to develop students' understanding and raise their awareness of what is essential for the construction of scientific explanations is also critical in meeting the needs of students. Learning how to generate well-formed scientific explanations must extend beyond purely learning the meaning of key concepts in Science. It involves being aware of the structures and language features that construct, connect and communicate scientific principles, knowledge in a coherent manner. Attention to how the language teachers use in class - whether in task and/or talk - can facilitate students' internalising and processing of content is invaluable. This works towards enhancing students' awareness as to the specifics involved in the process of interpreting and constructing explanations.

The study indicated the potential of the concrete measures to support students through explicit strategies to meet the literacy demands of scientific explanation through carefully designed scaffold task design integrated with skillful questioning and strategic managing of classroom talk and interaction. Active student engagement facilitated by concrete support scaffolds in various modalities (visual, textual, oral) and resources is aimed at enabling students to be actively involved in the process of learning. Teachers' pedagogic practice through crafting of students' tasks and interactive talk in specific contexts contribute to the dialogic process of knowledge co-construction and purposeful meaning-making.

The emergent findings are of particular relevance to teachers' professional development and learning which ELIS has drawn upon to support subject teachers in core curriculum courses, namely, 'Language awareness in the subject classroom' and 'Opening up talk for learning in subject classrooms' offered to schools on the WSA-EC programme. In addition, the findings have also benefitted other subject teachers who share similar concerns of their students' weaknesses in scientific explanations. This has scaled up the impact of the work from the school which is interested in extending support to other Science teachers within the school and beyond. A growing interest in collaborative school-based research among subject teachers in other schools facilitated by ELIS and other research partners from the National Institute of Education and MOE Divisions is evident. It is hoped that more of such school-based inquiry will enable teachers to build on their current practices and develop their ability as effective communicators, and to deepen their understanding of relevant literacy strategies to support their students' learning in the respective subjects.

We acknowledge that this study, at this point in time, was essentially limited to work within a regular school curriculum that involved a relatively small community of learners and teachers in the classes involved within a specific school context. We believe, however, that the study has demonstrated the potential of carefully designed pedagogic practice, particularly in task design and classroom discourse, to meet targeted learning objectives. More studies of this nature can deepen understanding and develop a fuller appreciation of the potential and impact of language-support strategies on students' learning with specific relevance to scientific explanations.

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