ENGLISH LANGUAGE INSTITUTE OF SINGAPORE

SUBJECT LITERACY

INQUIRY DIGEST

ISSUE 4
2019

FOREWORD

*What knowledge and skills do we as teachers need to enable our students to bridge the gap between current understandings and valued outcomes? **

Using this question to guide their inquiry, EC Champions and their colleagues have sought to deepen their learning of subject literacy and classroom talk, often by forming Professional Learning Teams and engaging in collaborative classroom inquiry with support from ELIS. This issue of *Subject Literacy Inquiry Digest* features the work of three such teams, whose members explored the use of talk or language support strategies in Primary Mathematics and Science, and Geography classrooms. The following articles capture their ideas and learning, which I hope will benefit and inspire all who are on a similar quest to improve student learning.

Do contact us at moe_elis_academy@moe.gov.sg if you wish to take on similar inquiry projects or ask for our support in other ways. We would be happy to assist.

Ms Caroline Anne Yeow
Deputy Director, Subject Literacy
ELIS

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ACKNOWLEDGEMENTS

The editors would like to thank Master Teachers Ms Lim Puay Yin and Dr Tan Liang Soon for reviewing the articles.

*Teacher inquiry and knowledge-building cycle to promote valued student outcomes. (Reprinted from *Teacher professional learning and development* (pp. 26-7), by H. Timperley, 2008, Brussels, Belgium: International Bureau of Education. Copyright 2008 by UNESCO International Bureau of Education. Reprinted with permission.)

Exploring the Use of Talk Moves as a Professional Learning Team

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INQUIRY FOCUS

A Professional Learning Team (PLT) comprising a group of teachers and EC Champions explored how talk moves could be used to promote student learning. This article features the work of the PLT leader, a Geography teacher, and how he inquired into his classroom practice to develop students' geographical skills such as describing, explaining and interpreting geographical data (CPDD, 2012), with support from ELIS consultants. It outlines the lessons learnt by the PLT about what it takes for talk moves to be used effectively in the classroom.

BACKGROUND

Research on talk in the classroom has shown that although students' talk plays an important role in their learning, teachers often do most of the talking in class, leaving students with limited opportunities to engage in extended academic talk (Alexander, 2005; Lim, 2018; Mercer & Hodgkinson, 2008; Towndrow, Kwek & Chan, 2015). Students therefore have limited opportunities to develop their thinking through talk or engage in collaborative learning. Moreover, many of the questions teachers tend to ask are closed-ended, forming the first part of a typical interactional pattern known as Initiation-Response-Evaluation (IRE) (Cazden, 2001).

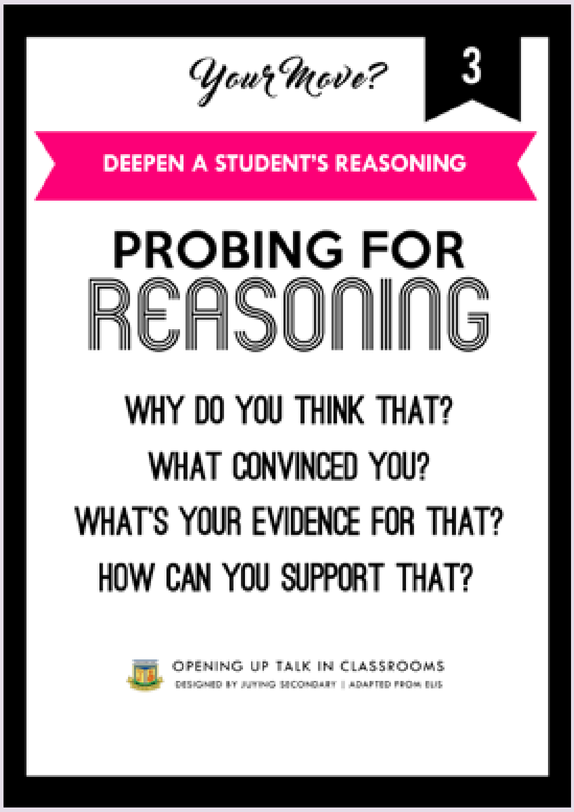
In contrast, dialogic teaching usually involves longer interactions between a teacher and students that are designed to help students "build understanding, explore ideas and practise thinking through and expressing concepts" (Scott, Meiers & Knight, 2009, p. 2). Dialogic teaching has been found to be most effective in leveraging the power of talk to develop thinking skills and promote deep student learning (Alexander, 2005; Scott, Mortimer & Aguiar, 2006). This raises the question of how teachers can create a classroom environment that supports students' reasoning and critical thinking. Researchers have proposed the use of strategic teacher actions, such as talk moves, which are intended to encourage student participation in the classroom in respectful and academically productive ways (Michaels & O'Connor, 2012).

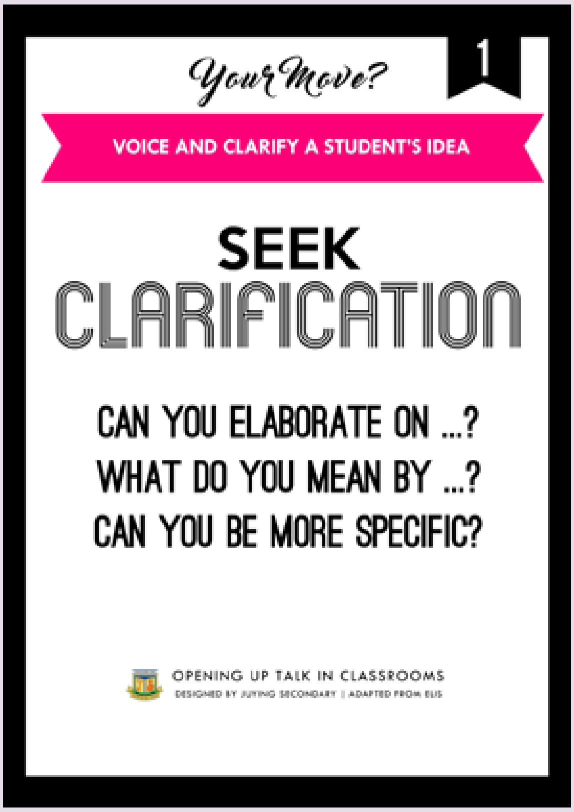
PROCEDURE

A Professional Learning Team (PLT), comprising a group of teachers and three EC Champions, wanted to deepen their understanding of the use of talk moves in subject classrooms after learning about them at a workshop conducted the previous year. While aware of the benefits, they were also concerned about the potential challenges such as lack of time and uncertainty over how to ask questions to promote thinking.

In consultation with ELIS, each PLT member inquired into his/her own use of talk moves. Guided by the Teacher Inquiry Cycle adapted from Timperley, Wilson, Barrar, and Fung (2007), each PLT member planned for and implemented the use of talk moves in his or her own subject classroom. They were guided by the following inquiry question: *How can talk be used successfully in a subject classroom to promote student learning*?

The PLT also leveraged the talk moves posters (see Figure 1) which had been created by the school's EC Champions after they participated in *Opening Up Talk for Learning in Subject Classrooms*, a professional learning course conducted by ELIS. As these posters were placed in every classroom, they served as a useful reference for the PLT members when using talk moves in the classroom.





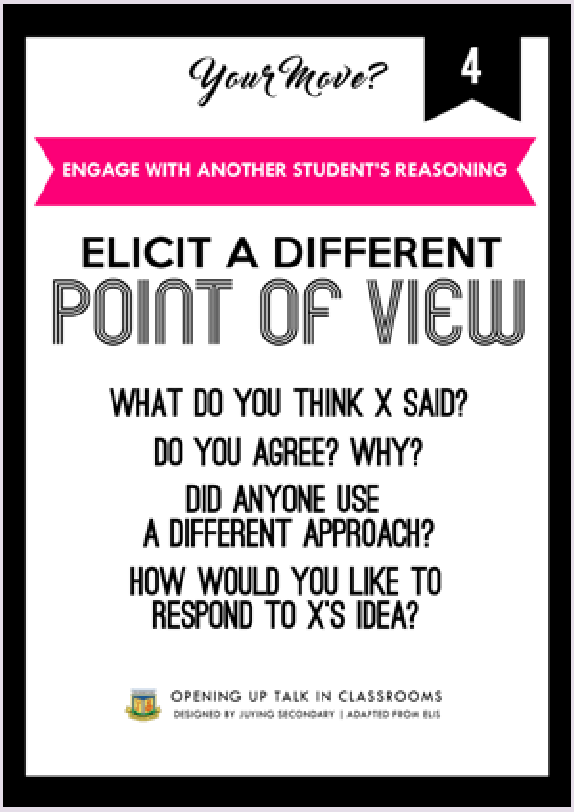


Figure 1. Selected talk moves posters produced by EC Champions.

It was agreed that the PLT leader would be the first to try out the use of talk moves in one of his Geography lessons with a mixed-progress Secondary Two Express class of 41 students. He transcribed and analysed a classroom discussion and shared his findings at the next PLT meeting.

Prior to conducting the class discussion on *Learning about the Impact of Traffic Congestion*, the PLT leader showed his students a video highlighting the three reasons how the economy had lost money due to traffic congestion. Figure 2 shows a part of the classroom transcript of the lesson with the Secondary Two Express students after they had watched the video.

Speaker	Lesson Transcript	Talk Move	Observations
Teacher	Who can point out the three reasons the economy lost money?		Teacher asks an initiating question to trigger the discussion.
Student 1	Traffic congestion.		Student 1 gives a short two-word answer and does not elaborate.
Teacher	Yes, why "lost money"?	*Probe for reasoning or evidence*	
Student 1	Fixing of infrastructure and vehicles.		Student 1 does not give much elaboration.
Teacher	Yes. What else?	*Guide a student to build on another student's contribution*	
Student 2	Pollution.		Student 2 also gives a short one-word answer without providing details.
Teacher	Pollution due to…?	*Probe for reasoning or evidence*	
Student 2	Carbon dioxide?		Student 2 again gives a short two-word answer and sounds uncertain.
Teacher	What sort of pollution is that?	*Seek clarification*	
Student 2	Air pollution.		

Figure 2. Excerpt of classroom transcript of the first Geography lesson.

Drawing on the lesson transcript (Figure 2), the PLT leader shared his reflections on the lesson at the next PLT meeting. Firstly, he observed that his students had experienced some difficulty in responding to his use of talk moves as they were not used to participating in a whole-class discussion. He recommended establishing routines such as having ground rules for productive academic discussions, in order to help create a supportive environment for students to speak in class. Secondly, he realised that students had difficulty providing extended answers. He thought that providing opportunities for students to discuss in pairs or small groups prior to a whole class discussion might help them come up with more substantial responses and better prepare them to contribute during the class discussion.

During a second inquiry cycle, the PLT leader worked with ELIS consultants to co-construct a Geography lesson for one of his Secondary Four Express classes. In this lesson, he planned to use talk moves to help his students articulate their geographical reasoning when answering data-response questions on *Map Distribution*, which involved the skill 'Explain with Evidence'. To help students prepare for the whole-class discussion, he planned opportunities for students to discuss their responses to a task in groups before conducting a whole-class discussion. He continued using talk moves with his students so as to build the culture of talk in the classroom. As with the first lesson, he transcribed and analysed the whole-class discussion, with support from ELIS consultants. The PLT leader also collected written reflections from his students about what they had learnt through the class discussion.

FINDINGS

This section reports the findings from the second inquiry cycle as well as student perspectives on how the use of talk moves had supported their learning. It also highlights the learning points from the other PLT members who embarked on their first inquiry cycle on the use of talk moves in their subject classrooms.

LESSONS LEARNT BY THE PLT LEADER WHEN APPLYING TALK MOVES

An analysis of the transcript from the second Geography lesson led the PLT leader to identify three factors that had enabled talk to be successfully used to promote student learning.

1. Students needed adequate knowledge to bring to the class discussion. This meant that they needed to be given time to think about and prepare for discussion points before a whole-class discussion could be conducted. This thinking time enabled the students to provide more extended responses to the teacher's questioning. For example, in the lesson transcript excerpt below (see Figure 3), Student 1 was able to provide an extended answer to the question because he had had the opportunity to discuss it with his classmate, think about his ideas and write his points down beforehand.

Speaker	Lesson Transcript	Talk Move	Observations
Teacher	So S1, could you share with us another point?	*Guide a student to build on another student's contribution*	
Student 1	Indonesia will suffer more than Malaysia from earthquakes as… Indonesia suffers more earthquakes… and this makes it more impactful for Indonesia due to the higher frequency of earthquakes. Uh, so due to the frequent number of earthquakes -		
Teacher	Ok, I'm going to write this down. [Teacher writes down the points] "Due to the greater number of earthquakes…?"		Teacher looks expectantly at the student for elaboration.
Student 1	Um, it causes more damage to important infrastructures, and therefore harder for the country to recover back in terms of economic stability.		

Figure 3. First excerpt of classroom transcript from the second inquiry cycle.

2. The teacher observed that when he refrained from evaluating students' responses, and instead, elicited other students' views, he was able to engage other students to think more critically about a concept (see the excerpt from lesson transcript in Figure 4). This benefitted both the student who produced the correct response, and the rest of the students who were listening to the discussion. Scott et al. (2009) highlight that students do not have to be directly involved in a discussion to benefit from it; simply "watching another student participating in a dialogue with a teacher or a more knowledgeable peer has powerful effects on learning". In this case, Student 2 was able to critically evaluate another group's response to point out that the other students had not used Figure 9 when explaining why more earthquakes occurred in Indonesia.

Speaker	Lesson Transcript	Talk Move	Observations
Teacher	Ok what do the rest of you think?	*Elicit a student's view on another student's idea*	
Student 2	Um, they never use the Figure 9.		Student raises a relevant and important point.
Teacher	They never use the Figure 9.		
Student 2	They never explain why Indonesia has more earthquakes.		Student builds upon earlier point to provide a more detailed response.
Teacher	They never explain why Indonesia has more earthquakes. I'm going to highlight that part here. It's missing some information. How do we know that Indonesia suffers more earthquakes? How does the figure substantiate your answer? Ok, that is what's missing.		

Figure 4. Second excerpt of classroom transcript from the second inquiry cycle.

3. The PLT leader found that he could guide students towards deeper learning when he encouraged them to build on one another's answers and provided sufficient wait time for them to think. For example, in the lesson transcript excerpt below (see Figure 5), the teacher responded to Student 1's point with a question and was not put off by the lack of an immediate response from the students. He also did not evaluate student answers that were incomplete. Instead, he sought clarification, probed for reasoning and invited other students to contribute their perspectives. This allowed the students to develop their initial answers to include an important detail about the magnitude of earthquakes (see Student 5's answer at the end of the transcript).

Speaker	Lesson Transcript	Talk Move	Observations
Student 1	But we already said there is a higher frequency.		Student 1 defends his earlier answer with a point that is correct, but incomplete.
Teacher	There is a higher frequency. Ok, does anyone agree or disagree whether this is a valid point?	*Elicit a student's view on another student's idea*	Teacher does not immediately evaluate whether 'higher frequency' is a valid point.
Students	*pause* no answer		Teacher observes wait time.
Teacher	S3, is 'higher frequency' here actually an evidence, in your opinion? Does this actually help to substantiate this point – "Indonesia suffers more earthquakes"?	*Elicit a student's view on another student's idea*	
Student 3	Yes		
Teacher	So yes, the higher frequency is actually an evidence?	*Re-voice for verification*	
Student 4	It is not higher frequency.		
Teacher	If it's not higher frequency, so what is it?	*Seek clarification*	
Student 4	They need to mention the magnitude of the earthquakes.		Student 4 raises a different point from the one made by Student 1 earlier.
Teacher	Ok so what S4 is saying is that it is not about the frequency, it is actually about the magnitude. Do you agree? What do you think?	*Elicit a student's view on another student's idea*	
Student 5	No…		
Teacher	Ok, S5 says no. No to what?	*Seek clarification*	
Student 5	It should be 'higher frequency of earthquakes of magnitude greater than 5'.		Student 5 builds on both Student 1's and Student 4's earlier responses to articulate a more comprehensive answer.

Figure 5. Third excerpt of classroom transcript from the second Geography lesson.

REFLECTIONS BY STUDENTS ON WHAT THEY HAD LEARNT

Feedback from students showed that they had developed a deeper understanding of the concepts and become clearer about the steps required to complete the data-response questions.

Student 1	I have learnt that I have to ensure I use the figure to show evidence after I state my reasons, since the question stated "With the help of Figure 9".
Student 2	Important points that are related to the question focus must be stated clearly and backed up by evidence/data from the map distribution. Data provided should be explained and linked back to the question focus.
Student 3	To compare, I need to give reasons and evidence. I also need to use superlatives like 'most', 'least', 'greatest' and 'smallest'.

PLT MEMBERS' REFLECTIONS ON THEIR USE OF TALK MOVES

Just as the PLT leader had done, the other PLT members also reflected on their use of talk moves:

TEACHER 1 (MATHEMATICS)

The effectiveness of talk moves depends on planning and sequencing of questions, anticipation of possible responses and planning of further questions based on these responses. Talk moves used effectively can help to promote students' engagement to support teaching and learning, while revealing learning gaps for targeted teacher feedback and action.

TEACHER 2 (ELEMENTS OF BUSINESS STUDIES)

Through the PLT session, I learnt the importance of extracting answers, questions or feedback from students during lessons to ensure they are in tune with the lesson. After the PLT sessions, we used certain frames for prompting many more times than usual, to deepen students' reasoning and guide students to build on other student's contribution.

TEACHER 3 (SCIENCE)

As I began to incorporate talk into as many of my lessons as possible, it made me more confident of using talk moves for various reasons and types of learners. Through this PLT journey, I was able to see how talk moves impacted my students. The students became more engaged and confident in their scientific reasoning.

TEACHER 4 (PRINCIPLES OF ACCOUNTS)

I get to examine my students' thinking and correct their misconceptions on a timely basis. Talk moves have become a 'culture' for our lessons so much so that every student in the class is used to articulating his or her viewpoints when cued. It has improved the quality of our lessons.

TEACHER 5 (DESIGN AND TECHNOLOGY)

I became more aware of the types of questions to use and more conscious of the need to encourage students' responses to each other by allowing more wait time for students to respond. By listening to their responses and using appropriate talk moves, I was able to get other students to comment. In this way, I could get students to build on each other's ideas and create lively discussions.

HUMANITIES HOD

Through my observation of Dayan's lesson that incorporated talk moves, I found that talk moves are beneficial for teaching and learning. They help teachers to frame their questions, prompt the students and elicit responses from students. Talk moves scaffold and deepen students' learning. As students have an opportunity to voice and clarify their ideas, it serves as an effective tool to check their understanding too.

> Reflecting on the whole experience, the PLT leader said:
>
> *Being able to collaborate with ELIS on this Professional Learning Project on Opening Up Talk in the Classroom has been beneficial for me and my team this year. Not only did ELIS share about the Teacher Inquiry Cycle with us to help us with our individual professional development in the use of talk moves in our subject classrooms, they also clarified our understanding of what a Productive Academic Discussion (PAD) is. Personally, I got to co-construct a PAD activity with ELIS for a lesson and I got to witness how having a PAD in the classroom allowed my students to deepen their thinking and make their learning visible.*

DISCUSSION

Embarking on the collaborative inquiry project with ELIS enabled the PLT leader and the team to deepen their understanding of how to use talk moves effectively in their classrooms. Within the PLT, different members reported on the benefits and improvements to student learning brought about by their use of talk moves in the classroom.

Having learnt about and experienced using the Teacher Inquiry Cycle, the PLT members are now prepared to share their experience with the rest of their colleagues. They look forward to supporting colleagues in their professional development journey so as to help build a culture of effective communication in every classroom.

Acknowledgement

The authors would like to thank Ms Lim Puay Yin, Master Teacher/Geography, Academy of Singapore Teachers, for reviewing this article.

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Helping Primary Six Students Write Better Explanations in Science

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INQUIRY FOCUS

In order to help their students write better answers to open-ended questions in science, two Upper Primary teachers at Endeavour Primary School collaborated with ELIS to investigate ways to infuse language support into their lessons. This article reports on their joint inquiry into the effectiveness of their intervention strategies.

BACKGROUND

The need for literacy instruction in the science classroom has been advocated by scholars who have observed that learning science entails more than the acquisition of content knowledge (Gibbons, 2002; McConachie & Petrosky, 2010; Mojé, 2008; Seah, 2016; Wellington & Osborne, 2001). In order to be successful, students must also master the specific ways of reading, writing, thinking, talking and doing that are unique to science, all of which can be challenging for the uninitiated. The Singapore Primary Science syllabus identifies communication as a necessary skill for students to develop. Specifically, it recognises that students need to know how to transmit and receive information "presented in various forms – written, verbal, pictorial, tabular or graphical" (CPDD, 2013, p. 9). As language can be a significant barrier in learning science, science teachers need to provide support for not only the conceptual development but also the language demands of the subject. One way to do so is by explicit instruction – teaching students the aspects of language which can "foster active involvement" and "independence" in learning, reading and writing about science (Gibbons, 2002, p. 60). This can be achieved by providing a range of scaffolding strategies (such as word banks and sentence frames) within a structured framework of instruction that gradually releases responsibility from the teacher to the students (Fisher & Frey, 2008).

This study focuses on two science teachers' efforts to help their students write better explanations in science by providing them with scaffolds for using the appropriate language.

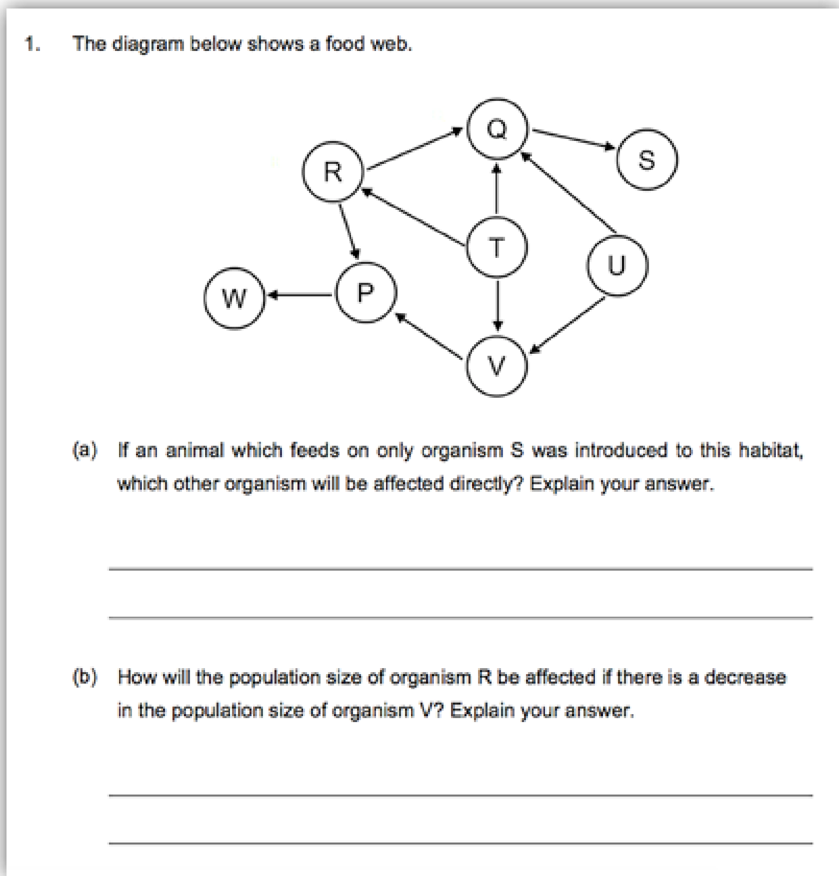
PROCEDURE

An EC Champion and his colleague had observed that their Primary Six students, even the high-progress ones, struggled to write accurate answers to open-ended questions in science, despite displaying an understanding of the concepts. With the support of an ELIS consultant, they decided to embark on a collaborative inquiry project to explore ways to infuse language scaffolding into a five-lesson unit on food chains and food webs. A total of 70 students from two Primary Six classes participated in the study which sought to answer the question, *What are the effects of providing language support on students' written answers for science open-ended questions*?

Informed by the Gradual Release of Responsibility model (Fisher and Frey, 2008), commonly known as the *I do - We do - You do together - You do alone* sequence of instruction, the teachers not only taught science concepts but also guided students to acquire the language needed to write accurate explanations for open-ended questions. As students had learned about food chains and food webs earlier in the year, the teachers focused on revising the concepts in the first two lessons of the unit. The teachers then explicitly taught the students how to write explanations and provided language support and opportunities for practice in the next two lessons. In the final lesson, the teachers addressed common misconceptions and learning gaps that persisted.

To ascertain the effects of their intervention on student learning, a set of questions on food webs (see Figure 1) were given before and after students were exposed to the language support strategies (just before lesson three and immediately after lesson four). Student answers to both assessment exercises were analysed to check for accuracy and learning gaps, whether conceptual or linguistic.

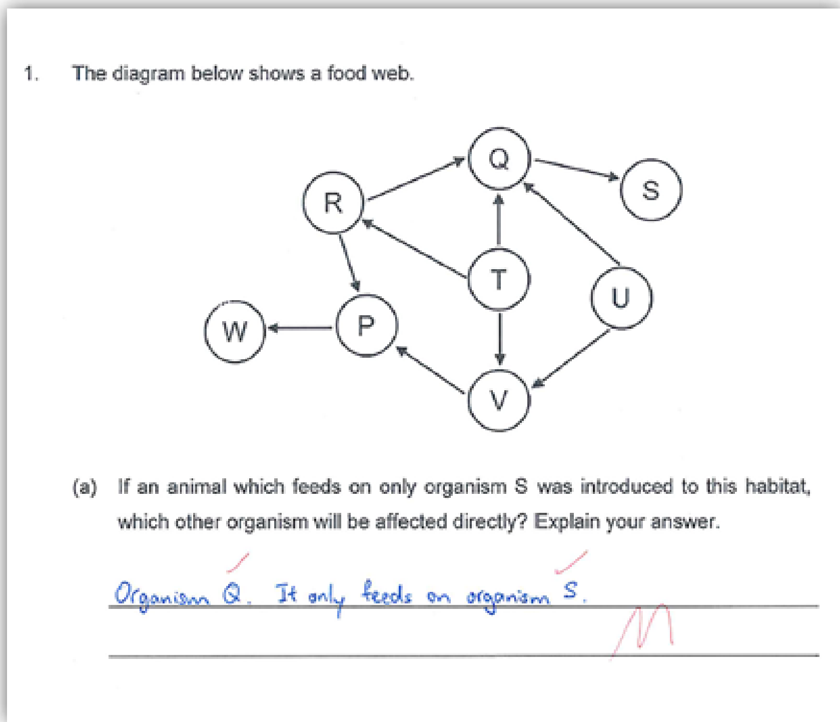
As expected, student answers in the pre-intervention assessment were mostly brief and inadequate. While some demonstrated an uncertain grasp of the concepts, many displayed a lack of knowledge about the conventions and language needed to write an explanation about the relationships among organisms in a food web (see Figure 2). Consequently, the teachers spent the next two lessons attending to both the conceptual and linguistic needs of the students. The following section reports on how the teachers addressed the students' language needs.


1. The diagram below shows a food web.

(a) If an animal which feeds on only organism S was introduced to this habitat, which other organism will be affected directly? Explain your answer.

(b) How will the population size of organism R be affected if there is a decrease in the population size of organism V? Explain your answer.

Figure 1. The pre- and post-intervention assessment questions.


1. The diagram below shows a food web.

(a) If an animal which feeds on only organism S was introduced to this habitat, which other organism will be affected directly? Explain your answer.

Organism Q. It only feeds on organism S.

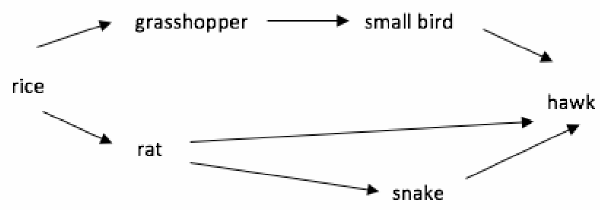
Figure 2. An example of a student's incomplete answer on the pre-intervention assessment worksheet. The student merely repeated the information given in the question, stating what the animal ("it") did as a reason for why organism Q would be affected.

PROVIDING LANGUAGE SUPPORT

I DO

In response to their students' learning needs, both teachers taught their students how to write an explanation by making explicit the language used in constructing one. Using a different question about the food web, they deconstructed a written answer, making the explanation structure and language features apparent to the students (see Figure 3). Using Model Thinking Aloud, a teaching action in the Singapore Teaching Practice, the teachers verbalised their thought processes as they worked on the task, showing students how they applied key concepts while they constructed an answer to the question. They also explained their language choices, beginning with the overall cause-effect structure of the answer and continuing by showing how they would fit their science content ideas into this structure. Next, they focused on their word choices, referring to a list of content vocabulary items essential to the topic which they had previously co-constructed with the students. The list contained words and expressions such as *increase*, *decrease*, *prey on*, *feed on*, *organism X*, *the population of X*, as well as comparative words such as *fewer*, *less* and *more*. The teachers emphasised that the words were necessary for communicating with precision and accuracy in science. To help their students join the words together into a meaningful explanation, the teachers also introduced sentence frames that showed how connectives such as *hence* and *because* could be used to express the cause-effect relationship between clauses (see Figure 4).

Q1. The diagram below shows a food web in a rice field.



The farmer killed all the rats in the rice field.

(a) How will the population of snakes be affected? Explain your answer.

The snake feeds on the rat only. When all the rats were killed, the snakes have no prey to feed on. Hence, they will die of starvation and the population of snakes will decrease.

Concept	Prey-predator relationship. When there is no prey, there is no food for the predator.
Cause	The snake feeds on the rat only. All the rats were killed.
Effect	The snakes have no prey to feed on. Hence, they will die of starvation and their population will decrease.
Final answer	The snake feeds on the rat only. When all the rats were killed, the snakes have no prey to feed on. Hence, they will die of starvation and the population of snakes will decrease.

Figure 3. The question and the language scaffolding used for teacher demonstration. Content vocabulary items are highlighted in yellow while the connectives are shaded green.

Sentence Frames

As ________ (cause), so ________ (effect).

When ________ (cause), ________ (effect).

________ (cause). Hence, ________ (effect).

________ (effect) because ________ (cause).

With ________ (cause), ________ (effect).

________ (cause). As such, ________ (effect).

________ (cause). That is why ________ (effect).

Figure 4. Sentence frames with connectives that can be used to express cause-effect relationship.

WE DO

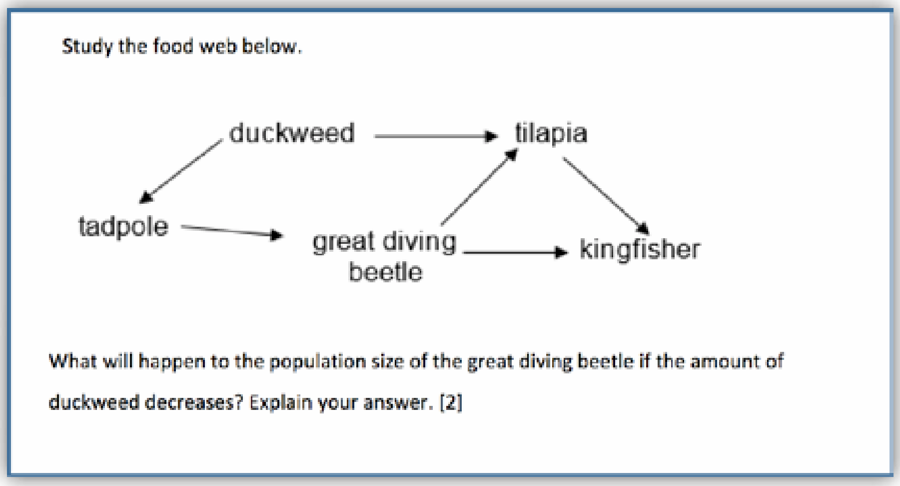
After the teachers had modelled thinking aloud, the students were introduced to another question on the food web. For this question, the teachers worked with the students on an answer, coaching them through the entire thinking and writing process. As they co-constructed their answer line by line, students could apply what they had just learnt with the help of the teacher.

YOU DO TOGETHER

Next, the teachers designed another question for students to work on in small groups (see Figure 5). The students co-wrote their answers, using the cause-effect frame, vocabulary list and sentence frames as scaffolds. The teachers analysed students' answers to determine learning gaps, then designed another group task to address those gaps. This task required students to critique two answers, both of which were constructed by the teachers. One contained common errors while the other was an exemplar. Students were asked to identify the cause-effect language and check for clarity and precision in the vocabulary use (see Figure 6). They presented their analyses to the class and participated in a whole-class discussion about the best ways to improve the flawed answer. Figure 7 illustrates how one group represented their critique on the worksheet.

YOU DO ALONE

An individual writing task was given to students at the end of the unit to assess their learning and to ascertain the effects of the intervention. This comprised the same set of questions given at the start of the unit.


Study the food web below.

What will happen to the population size of the great diving beetle if the amount of duckweed decreases? Explain your answer. [2]

Figure 5. The question for group writing.

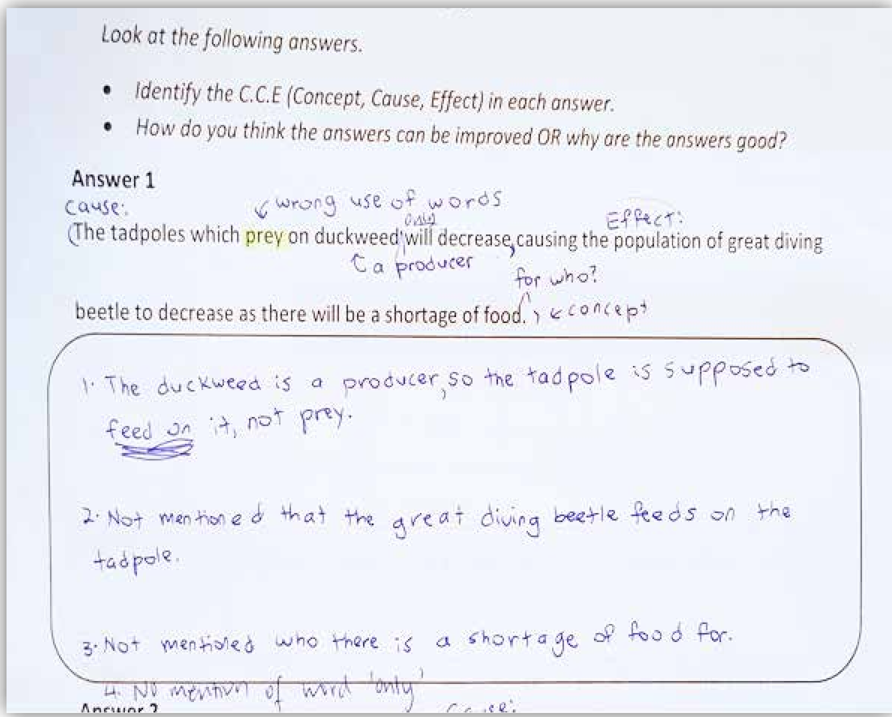
Look at the following answers.

- Identify the C. C. E. (Concept, Cause, Effect) in each answer.
- How do you think the answers can be improved OR Why are the answers good?

Answer 1
The tadpoles which prey on duckweed will decrease causing the population of great diving beetle to decrease as there will be a shortage of food.

Answer 2
When the amount of duckweed decreases, the tadpoles will also decrease in population as they feed only on duckweed. Hence, the great diving beetle which feeds on tadpoles only will have less food to feed on and its population will decrease.

Figure 6. The answer-critique task (group work).


Look at the following answers.

- Identify the C.C.E (Concept, Cause, Effect) in each answer.
- How do you think the answers can be improved OR why are the answers good?

Answer 1
Cause: wrong use of words only Effect:
(The tadpoles which prey on duckweed will decrease, causing the population of great diving
a producer for who?
beetle to decrease as there will be a shortage of food.) concept

1. The duckweed is a producer, so the tadpole is supposed to feed on it, not prey.
2. Not mentioned that the great diving beetle feeds on the tadpole.
3. Not mentioned who there is a shortage of food for.
4. No mention of word 'only'

Figure 7. A group's response to a part of the answer-critique task.

FINDINGS

An analysis of the answers in the post-intervention assessment showed that students were able to write better explanations at the end of the unit. Their answers were substantially more accurate, and demonstrated the use of precise vocabulary and sentence frames.

While only a small number of students wrote adequate answers for Questions 1(a) and 1(b) prior to the intervention (20% and 14% respectively), many more of them produced good answers at the end of the unit (84% for Question 1(a) and 72% for Question 1(b)). For example, the student whose brief answer was shown earlier (in Figure 2) was able to write a more substantial answer after the intervention (see Figure 8).

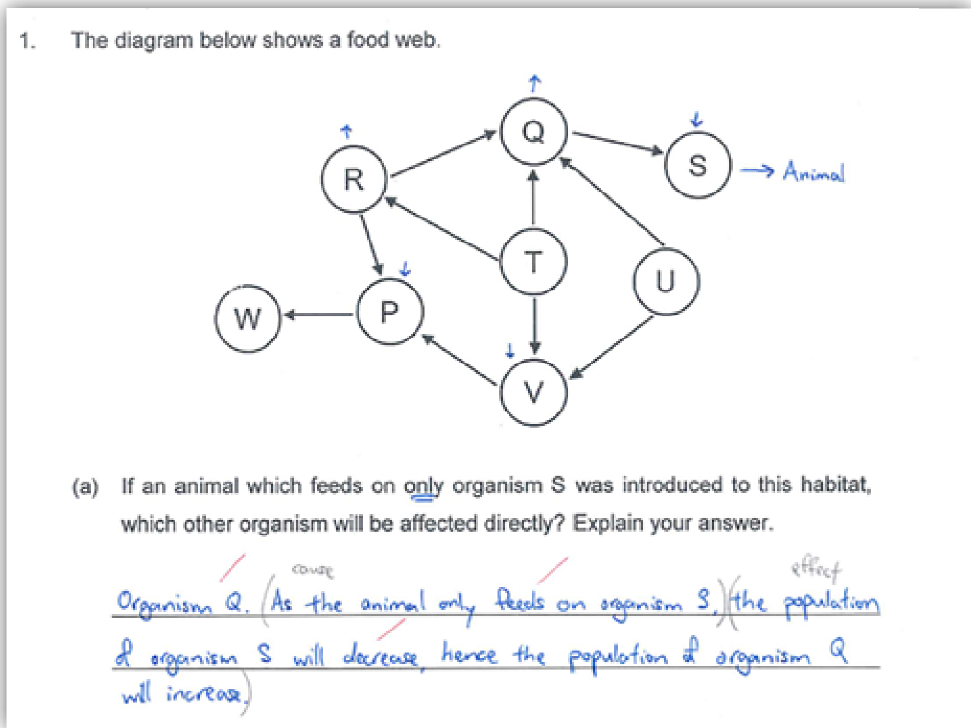


Figure 8. An improved answer showing annotations used by the student to identify the cause and effect elements in the explanation.

The intervention, however, did not seem to produce a positive effect on some students – 16% for Question 1(a) and 28% for Question 1(b). Interviews with the students and a closer inspection of their answers revealed three reasons for the persistently weak or weaker answers: students who chose not to use the recommended vocabulary or writing frames, students who expressed difficulty in reading the food web and students who were confused about the scientific concepts. After careful interpretation of the findings, the teachers were able to design follow-up lessons that addressed the learning gaps.

DISCUSSION

This inquiry allowed the teachers to explore the use of language scaffolding for the teaching of science, specifically in writing explanations. The teachers, whose teaching previously focused on concepts and key words, were able to observe, first-hand, the benefits of addressing the language demands of question tasks alongside concept instruction. They appreciated how quickly most students were able to write more detailed explanations when the language features of an answer were made apparent and the explanation structure was explicitly taught. Combined with the use of teacher modelling, guided instruction, collaborative learning and classroom discussions, this approach to teaching writing in science allowed the teachers to achieve substantial learning gains. Although some students appeared not to have benefited from the intervention, their learning gaps were made more apparent through this inquiry so that the teachers were able to address them in a timely and customised way. As a result of this inquiry, the teachers were so convinced of the importance of providing language scaffolding that the strategies were extended to other topics. In fact, language support strategies are now a mainstay of the science curriculum in their school.

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This study was presented at the International Science Education Conference 2018.

Making Students' Mathematical Thinking Audible and Visible through Students' Think-Alouds

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INQUIRY FOCUS

Primary Mathematics teachers from three schools observed that their students faced difficulties in using mathematical language to clearly articulate their mathematical thinking. With the support of ELIS consultants, the teachers aimed to sharpen students' mathematical thinking and help students express mathematical ideas clearly – core skills that have been identified in the Mathematics syllabus (MOE, 2012). The research questions guiding the teachers' inquiry were: How can teachers use students' think-alouds to enable students to verbalise their thinking in Primary Mathematics? How can teachers help students to engage in peer feedback for other students' think-alouds? What are the benefits of the use of students' think-alouds and peer feedback?

BACKGROUND

The Mathematics syllabus (CPDD, 2012) makes explicit the need for students to communicate effectively, stating that communication "helps students develop their understanding of mathematics and sharpen their mathematical thinking" (CPDD, 2013, p.17). Communication in mathematics refers specifically to "the ability to use mathematical language to express mathematical ideas and arguments precisely, concisely and logically" (CPDD, 2012, p.15). This implies that teachers need to provide opportunities for students to make their thinking processes audible and visible. Think-alouds require teachers, or students, to verbalise their thoughts in real-time (Martin & Wineburg, 2008). The benefits of doing this include making mental processes visible to students (Jeffrey, 2001) and providing a way of recalling and studying processes of thinking (Pressley & Afflerback, 1995). Studies have indicated that think-alouds scaffold students' thinking and learning at a higher level (Charters, 2003; Ortlieb & Norris, 2012). Think-alouds have been adopted for problem-solving in mathematics and helped students to verbalise what they were thinking and doing throughout a problem-solving process, even students who had learning disabilities (Rosenzweig, Krawec, & Montague, 2011).

One way to capture students' think-alouds is through the use of screencasts, that is, "screen capture of the actions on a user's computer screen, typically with accompanying audio" (Educause, 2006, p.1). Screencasts help teachers gain an understanding of a student's final answer, as well as the student's reasoning while solving a mathematical problem (Soto, 2015; Soto & Ambrose, 2014; Thomas, 2017). Using the evidence of student thinking elicited by screencasting, teachers can assess learning formatively and modify classroom instruction, either during the lesson or when planning for instruction in subsequent lessons (Thomas, 2017).

The study described in this article drew on social constructivist theories of learning (Perkins, 1992; Vygotsky, 1978) that view learning as an active process by which learners construct knowledge on their own and reflect on this experience. The teachers had a shared interest in wanting to help students sharpen their mathematical thinking as they engaged in solving mathematical word problems.

PROCEDURE

This section presents the context for the inquiry and describes how the teachers integrated the use of students' think-alouds into their classroom practice.

SCHOOL CONTEXT

The study involved three mainstream primary schools. Information on the schools, teachers and students involved is captured in the following table:

School A (Average to high socioeconomic background)	School B (Average socioeconomic background)	School C (Average socioeconomic background)
• Two teachers involved • One high- and middle-progress Primary Four class • Two high- and middle-progress Primary Three classes	• Three teachers involved • One high-progress Primary Four class • One middle-progress Primary Four class • One low-progress Primary Four class	• Four teachers involved • One high-progress Primary Four class • One mixed-progress Primary Four class

The teachers planned the integration of students' think-alouds into their lessons, given their shared interest in helping students to sharpen their mathematical thinking as they engaged in solving mathematical word problems.

The lessons comprised the following steps:

Teacher provided guiding questions for Polya's approach to mathematical problem-solving and modelled the think-aloud for a word problem. → Students created screencasts to capture their think-alouds for solving a word problem. → Students provided feedback on their peers' think-alouds.

With the guidance of ELIS consultants, teachers examined students' think-alouds using a framework developed to support students in verbalising their mathematical thinking. The framework made explicit the steps involved in the problem-solving process and how students were supported in verbalising their thinking in a systematic manner.

Teachers from School A aligned their guiding questions with the four steps of Polya's (1945) problem-solving approach (see Figure 1). The questions for students served to alert students to key considerations as they planned their think-alouds. The questions for teachers aimed to elicit students' responses while the students reflected on how they could make their thinking explicit.

The teachers from School B used a template that provided sentence frames to scaffold students' think-alouds. The scaffolds were designed to help students interpret each question, articulate why a chosen strategy (such as using a comparison model method) was helpful, state what the strategy enabled students to find out, and finally, reflect on the necessary checking of the answer (see Figure 2).

Polya's 4-step problem solving approach	Questions for Students	Questions for Teachers
Read and understand	• Have I used Structured Questioning? • Have I used chunking to identify key information? • Can I restate the problem by drawing a picture or diagram to help me understand the problem?	• Who (What) is/are in the story? What do they have? How many are there? • Who (What) has/is more/less? What makes you say that? • What happened? What did he do? What makes me say that? • Are there 1 or 2 situation(s)? • Who (What) is repeated? • Is there a change, what is the change? If not, what remains the same? • What am I trying to find out? • Have I left out any other important information?
Plan	• What strategy or heuristics can I use to solve the problem? • What makes you say that?	• Why do you think that? • What convinced you? • How did you come up with that answer/solution? • What's your evidence for that?
Carry out the plan	• Did I label my steps? • Did I use the right mathematical symbols? • If I am stuck, do I have an alternative method? • What makes you say that?	• Is that the only way to explain it? • Can you think of a counter method? • But what about…? • Does it always work that way? • Are you sure that …? • Did anyone use a different approach? • Who has a similar/different idea about how this works? • What might be other views/solutions?
Check	• Does the answer make sense? • Have I used Claim-Connect-Confirm (CCC) to check for reasonableness and accuracy? • Have I checked for calculation errors? • Have I checked for transfer errors? • Have I transferred information correctly? • Have I included the correct standard units?	• Who has the same answer as this? • Who has a different solution? • Are everybody's results the same? • Why/why not? • Have you thought of another way this could be done? • Do you think we have found the best solution?

Figure 1. Polya's (1945) problem-solving approach for mathematical word problems with guiding questions, used in School A (Chua, 2018, p. 54).

Hi everyone, my name is ___________ from 4/5. Today I will be explaining to you how to solve the following question.

*Read out the question.

Based on my understanding of the question,

Step 1

I can tell that there are _______ people/objects in this question.

- We are comparing the __________.
- We need to find out how ______________.

Step 2

I think that using (a model/drawing a comparison table) will be a good strategy to help us to find out the total/ difference/ the value of a unit. This allows me to see/visualise/compare __________.

Step 3

Based on the (model/drawing a comparison table) I have done, I can deduce/find out what is the total/difference/ the 1 unit?

Step 4

To check my solution, I will go through the following:

- Correct use of equal sign
- Correct units stated
- Correct calculation

To check my answer, I will see if it satisfies the conditions provided in the question by ……

Figure 2. Template for scaffolding students' think-alouds used by School B.

School A and School B used software such as *Explain Everything* or *Screencast-O-Matic* which facilitated the capture of image, text and talk input. The software also enabled teachers to make students' think-alouds available to others by exporting screencasts as mp4 files. Figure 3 shows a screenshot of a student's screencast and Figure 4 shows the transcript of the corresponding think-aloud.

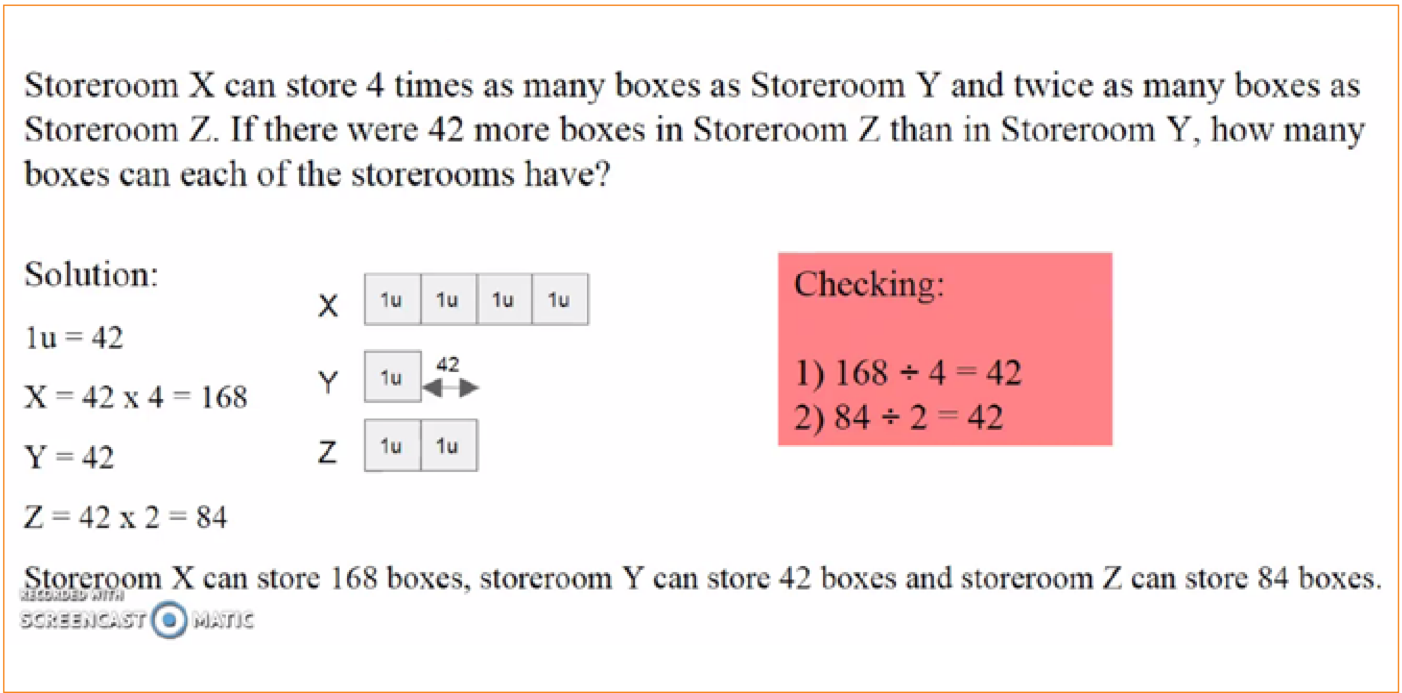

Figure 3. Screenshot of a student's screencast for a word problem in Mathematics.

Student's think aloud	Notes on what student does
Hello, this is ABC from P4 Thanksgiving and I am doing Question 2 of screencasting for Maths.	
Storeroom X can store 4 times as many boxes as storeroom Y and twice as many boxes as storeroom Z. If there were 42 more boxes in storeroom Z than in storeroom Y, how many boxes can each of the storeroom have?	
As (storeroom) X has 4 times as many boxes as storeroom Y, I shall draw 4 units for storeroom X and 1 unit for storeroom Y.	Student visually represents information given by drawing bar models.
And (storeroom) Z has 2 times more boxes than (storeroom) Y, I shall draw 2 units for storeroom Z.	
Now, I shall start labelling.	
The arrow at Y is equals to 42 as it is the same blank as 1 unit. 42 would also mean it is 1 unit.	Student solves the problem by representing the solution in mathematical statements and symbols.
X has 4 units so 42 times 4 equals to 168.	
Y has only 1 unit so it is still 42.	
Z has 2 units so 42 times 2 equals to 84.	
Now, I shall start checking.	Student checks solution to ensure solution is correct.
168 divided by 4 is 42. It is correct as 168 equals to 4 units of 42 and once it is divided it is still 42.	
84 divided by 2 equals 42. Tt is correct as 84 equals to 2 units and when divided it is still 42.	
Now, I shall say the final sentence.	Student reads out the final answer statement.
Storeroom X can store 168 boxes, storeroom Y can store 42 boxes and storeroom Z can store 84 boxes.	

Figure 4. Transcript of a student's think-aloud.

In School C, one teacher initially used a visualiser to record students' think-alouds. The recordings were saved on an SD card. However, this process proved too time-consuming as only one group of students could do their think-alouds at any one point, so the school used *Explain Everything* to capture the students' think-alouds.

The teachers also guided students' in self- and peer-monitoring of their think-alouds through the use of descriptors provided in the rubrics which the teachers had designed.

School B provided explicit descriptors, aligned with Polya's approach to mathematical problem-solving, for guiding students' self-monitoring (see Figure 5).

Self- & Peer-Evaluation Rubric for Problem-Solving

Objectives	Level 1 (Just Started) ☺	Level 2 (Getting There) ☺☺	Level 3 (Got it!) ☺☺☺
Understand the Problem	Need help to understand the word problem. Not able to identify all the key information and conditions given in the problem. Do not know what the question is asking to find. ☐	Able to restate part of the word problem. Able to identify some key information and conditions given in the problem. Know what the question is asking to find. ☐	Able to restate the entire word problem in own words. Able to identify all the key information and conditions given in the problem. Know what the question is asking to find. ☐
Devise a plan or strategy to solve the problem	Need help in identifying the key concepts of the problem. Not able to select the appropriate heuristics to help solve the problem. ☐	Able to identify the key concepts but need help in selecting the appropriate heuristics to help solve the problem. ☐	Able to identify the key concepts and decide on the appropriate heuristics to help solve the problem. ☐
Mathematical reasoning	Need help to explain the problem-solving process. ☐	Able to explain part of the problem-solving process using the key information given in the problem. ☐	Able to explain the entire problem-solving process using the key information given in the word problem and heuristics. ☐
Carrying out the Plan	Need help in the calculations to carry out plan and present workings correctly. ☐	Able to carry out some of the calculations in carrying out the plan and present parts of the workings correctly. ☐	Able to carry out the calculations and present all the workings correctly. ☐
Looking back (Reflection)	Do not know how to check whether the answer is reasonable. Do not know how to check if the answer satisfies all the conditions given. ☐	Able to check whether the answer is reasonable but do not know how to check if the answer satisfies all the conditions given. ☐	Able to check whether the answer is reasonable. Able to check if the answer satisfies all the conditions given. ☐

Figure 5. Descriptors for monitoring students' think-alouds (School B).

School C adapted an earlier framework used by School A to scaffold self- and peer feedback of students' think-alouds in areas specific to articulating the reasoning, applying the problem-solving method, and communication (see Figure 6).

		3 – Exceeding Expectations	2 – Meeting Expectations	1 – Below Expectations	Comments
MATHEMATICAL REASONING	**Ability to deconstruct demands of given task** • understand the problem **Qn: Did you reinterpret the question in your own words?**	❑ Able to interpret question in own words	❑ Able to interpret question by using some of the words from the question	❑ Reads aloud the given question of the task only without interpreting demands of the task.	❑
	Ability to apply problem solving method to be used / type of heuristics • account for the "WHAT" that was done and "WHY" **Qn: Did you state what kind of model you used and WHY?** **Qn: Did you explain your reasons for each step?**	❑ Explains reasons and decisions for each step clearly with details ❑ Shows clear links between visual representation, written working and verbal explanation	❑ Explains reasons and decisions for each step with some details ❑ Shows some links between visual representation, written working and verbal explanation	❑ States what was done without specifying details and reasoning for steps taken ❑ Does not show clear links between visual representation, written working and verbal explanation	❑
COMMUNICATION	**Accuracy in use of Mathematical language** • functional language that provide coherence to explanation. **Qn: Did you use the correct mathematical terms?**	❑ Uses specific Mathematical language accurately and in an excellent manner	❑ Uses specific Mathematical language appropriately	❑ Uses imprecise Mathematical language	❑
	Clarity and confidence in articulating mathematical reasoning **Qn: Did you talk loud and clear enough to be heard?** **Qn: Did you explain in a logical and organized manner?**	❑ Communicates in a clear and concise manner ❑ Explains in an organised and coherent manner	❑ Communicates in a clear and concise manner to a certain extent ❑ Explains in an organised and coherent manner to a certain extent	❑ Communicates in a lengthy yet unclear manner ❑ Explains in a disorganised and incoherent manner	❑

Figure 6. Descriptors for monitoring students' think-alouds (School C).

HELPING STUDENTS TO GIVE PEER FEEDBACK

Teachers helped students to give feedback on their classmates' think-alouds using different methods. In one method, they used guiding points in a 'word bank' (see Figure 7).

Word bank to guide students in peer feedback

- Interprets question
- Makes effort to check final answer
- Able to reason why using a model or table is better
- Explains the concept of constant difference should be used
- Shows clear links between visual representation, written working and verbal explanation
- Uses specific mathematical language accurately
- Communicates the explanation clearly
- Explains in an organised manner

Figure 7. Scaffolding peer critique and feedback through the use of a 'word bank' (school B).

In another method, the teachers gave out a template for students to record what they perceived as strengths ('two stars') and constructive suggestions for improvement ('a wish'). These helped students to respond to their peers' think-alouds and to elicit both observed strengths and weaknesses.

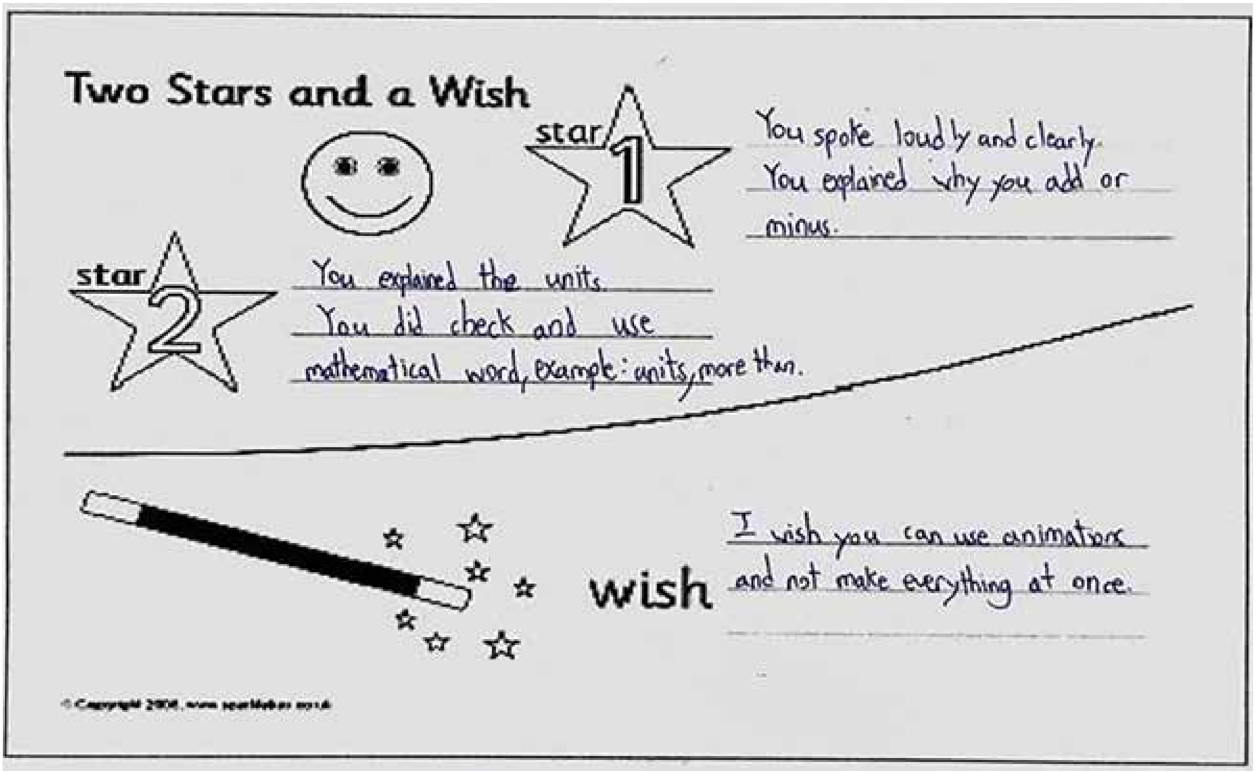

Figure 8. A student's response to another student's think-aloud.

FINDINGS

WHAT ARE THE BENEFITS OF USING STUDENTS' THINK-ALOUDS AND PEER FEEDBACK?

Teachers' perspectives on how the students' think-alouds influenced their teaching and the students' learning were elicited through individual teacher reflections. Some illustrative teacher responses are shown in the table below.

Specific benefit from students' think-alouds	Illustrative teachers' responses
Enable students' thinking to be made visible	When students think out loud, it allows teachers to understand their thinking process when problem-solving.
	I no longer need to speculate on the underlying reasons for why and how students came up with their solutions as their thinking has been made visible. The student's approach to problem-solving is of value to students' learning. In particular, drawing the comparison model allows them to see the relationship between the number of boxes in storerooms X, Y and Z (based on example in Figure 3).
Promote greater student engagement in learning, and develop student autonomy and ownership	Very motivated to make their think-alouds clear as they are excited to let their peers listen to and view their presentations.
	Use of screencasts in capturing students' talk allows maximum participation and increased engagement for everyone, even for shy students.
Enhance learning for students weak in mathematics	The biggest success for me was when a student, formerly from the Learning Support for Mathematics (LSM) programme, was able to understand the concept of 'fraction of a set' and presented his think-aloud pretty well.
	Guiding questions enabled the weaker students with language problems to verbalise their thinking aloud with confidence. They also benefitted by being able to 'see' their thinking process and areas where they had gone wrong.
	Showing strong students' think-alouds showcased good practices. For low-progress students, this exposure helped to raise their reasoning and communication skills as well as build up their confidence level.
Surface students' misconceptions for appropriate follow-up	Think-alouds provide a good platform for students to process their thoughts and for teachers to know if students are correct in their mathematical thinking.
	Helps me understand what students could have misunderstood or 'wrongly learned'. I become aware of the need to re-teach in order to address misconceptions surfaced. This information determines what and how I would design my next lesson and the pace of my teaching.
Provide opportunities for peer feedback and engaged learning through exchange of perspectives	Creates a platform for students' peer review where they learn to provide constructive feedback.
	I could see my low-progress students' enthusiasm in presenting their work and giving peer feedback although a lot of scaffolding is involved.

From these illustrative teacher responses, it can be clearly seen that teachers were able to monitor student progress in learning. They also developed greater student engagement and ownership, made evident students' misconceptions and promoted collaborative learning through peer feedback.

TEACHERS' PERSPECTIVES ON THE VALUE OF PEER CRITIQUE AND FEEDBACK

Teachers were convinced of the benefits of peer critique and feedback for students, as shown by the example comments below.

Teacher F: A quiet classroom is a bad classroom. Interacting with their peers helped with the students' learning too.

Teacher I: As they view more examples of their peers' work, be it exemplary or not, they are clearer with regard to the expectations and what constitutes clear mathematical communication, and are able to reflect on their own work.

Teacher J: To me, it serves as a form of formative assessment where students can assess each other's thinking.

Engaging students in peer feedback brought about tangible benefits as reported by both teachers and students, including low-progress students, in identifying their peers' language use, model drawing and problem solving approach.

By encouraging peer critique in this inquiry, students also learn to be more open to constructive feedback regarding their screencasts.

DISCUSSION

Participating in this inquiry enabled teachers to be resourceful in adapting materials developed for scaffolding mathematics students' think-alouds in a systematic manner. They also deepened their understanding of how to monitor students' attempts at verbalising thinking.

Teachers recognised the need for sustained practice in the use of think-alouds to reinforce the critical skills needed in solving mathematical word problems. In addition, they gained awareness of the specific changes required in their pedagogical practice. These included the need to intentionally foreground the use of students' think-alouds in mathematics lessons to support learning:

Teacher A:	I now pay attention to asking specific types of questions as well as take note of how students present and verbalise their answers. I set more time now for students to verbalise their thinking.
Teacher B:	I see the need to consistently adopt think-alouds to determine students' strengths and weaknesses and ensure that students learn.
Teacher C:	I allocate more time for students' think-alouds and peer feedback to sharpen students' reasoning and communication skills.

Teachers acknowledged the need for specific changes in their roles to build a supportive culture for students to have a greater voice in the mathematics classroom:

Teacher D:	I used to be a dictator in my mathematics class! I realise that it is important to allow students to talk to express themselves and present their answers. I now provide helping words and guiding questions to help students. I also encourage students to share alternative solutions or present their answers.
Teacher E:	I now try to focus more on student-centred lessons where I act more as a facilitator. The students learn to take ownership of their own learning and become the 'teacher' to one another.
Teacher F:	Teacher has to explicitly role model the use of mathematical language. Teacher also has to make a conscious effort to let this happen.

A positive classroom culture and environment is crucial so that students feel safe to share their thinking process at all times.

Three schools adapted the pedagogical approach and resources developed from an initial intervention in one school which was scaled up to the other schools to meet different students' learning needs. Teachers benefited from the strong collaboration and teamwork across schools, and recognised the value of engaging students in peer critique and feedback on each other's think-alouds.

Acknowledgement

The authors would like to thank Dr Tan Liang Soon, Master Teacher/Mathematics, Academy of Singapore Teachers, for reviewing this article.

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This study was awarded the MOE Innergy (Schools) Award 2018 and will be presented at MOE ExCEL Fest 2019.

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