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A Case Study of a Science Teacher's Knowledge of Students in Relation to Addressing the Language Demands of Science

Abstract

Learning science encompasses learning the language of science, which can pose considerable challenges to students due to its specialised features and structures. Addressing the 3-language problem (the need to transition between daily, general school and disciplinary languages) and the specific language demands of science thus constitutes part of the larger goal of promoting disciplinary literacy. Most studies have focused on the conceptual demands of science learning and have not examined what knowledge teachers require to support students' learning of the language of science. In this study, we focus on science teachers' knowledge of students (KS) for addressing the language demands of science. This qualitative case study has two aims: (1) to unpack a teacher's KS related to their language use in science; and (2) to uncover how this KS informs teaching practices. Transcripts of teacher interviews, lesson planning sessions and lessons drawn from two Grade 4 science classrooms taught by a primary science teacher constituted the data for this study. We identify five aspects of KS (i.e. prior knowledge of and about language, difficulties with language, abilities across modes of language and across subject areas, and learning progress) that inform four distinct teaching practices. This case study highlights and unpacks a dimension of KS that is often overlooked in the current literature on pedagogical content knowledge (PCK) for science teaching. The implications to teachers' PCK, science teaching and teacher professional development are discussed in light of the findings.

Key words: knowledge of students, language demands of science, pedagogical content knowledge (PCK) for disciplinary practice, teacher knowledge

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Introduction

Learning the language of science is not only important for accessing and communicating established scientific knowledge, it is also critical for participating in scientific practices and generating knowledge, skills that are increasingly valued in science education reforms (Lee, Quinn, & Valdés, 2013). Language skills in science learning and teaching include the ability to transition between everyday language (L1), general academic language (L2) and specific disciplinary language (L3), sometimes referred to as the 3-language problem (Yore & Treagust, 2006). Addressing the language demands of science thus constitutes part of the larger goal of promoting [1]disciplinary literacy, which "emphasizes the unique tools that the experts in a discipline use to engage in the work of that discipline" (Shanahan & Shanahan, 2012, p. 8). This study examines one such tool: scientific language. Few studies have focused specifically on the knowledge teachers require to address the language demands associated with learning science. We take a closer look at such specialised knowledge in this study, specifically teachers' knowledge of students (KS). KS is the "knowledge teachers must have about students in order to help them develop specific scientific knowledge" (Magnusson, Krajcik, & Borko, 1999, p.104). It is an important component of pedagogical content knowledge (PCK). However, current PCK studies of KS (e.g. Gess-Newsome, 2015) have tended to focus on teachers' understanding of students' (pre-)conceptions and/or difficulties related to the concepts rather than on students' [2]abilities to learn the language related to specific scientific knowledge.

This is a case study of one primary science teacher who is able to articulate how she uses her KS to address the language demands of science. Her application of KS in her science teaching practices allows us to explore, unpack and illustrate this aspect of KS. Two research questions guide this study. First, what is the nature of an experienced primary science teacher's KS related to addressing the language demands of science? Second, in what ways are her teaching practices informed by this KS? The insights gained from this investigation contribute to our understanding of the knowledge teachers require to address the language demands of science and the ways such knowledge may shape the instructional work for teaching disciplinary literacy. They should in turn inform subsequent targeted interventions and professional support for teachers in this area.

Literature review

The problem space of this case study involves teacher preparation to address the contemporary epistemic and traditional evaluative aspects of science instruction and learning in primary school classrooms. Two bodies of scholarship inform our study: (1) the language demands of science and (2) studies of PCK.

Language Demands of Science

Language, especially in written form, is a unique and powerful human attribute, but its specific nature and function vary across situations and purposes—talking with peers at a party, providing directions to complete a learning task, or arguing about an environmental issue using claims and evidence. Learning the language of science is thus important, as language serves multiple functions in science classrooms, including the following: (1) communicative – "a system for transmitting information", (2) epistemic – "an interpretive system for making sense of experience", and (3) rhetorical – "a tool for participation in communities of practice" (Carlsen, 2007, p. 68).

Diverse linguistic devices and strategies make scientific language distinct from the language used in other disciplines and daily life (Halliday, 2004), and learning the language can be challenging. The enterprise and procedures of science demand the use of conceptual labels and epistemic and ontological terms (metalanguage, such as "evidence" and "claim") to establish specific meanings (Shanahan, 2012, p. 44), in addition to a huge body of specialist vocabulary (Fang, 2006). Fang (2006) identified several features of scientific language that could pose a challenge to science learning: unique use of prepositions, conjunctions and pronouns; ellipses, subordinate clauses, prepositional phrases, abstract nouns, lengthy nouns and complex sentences; interruption construction; and passive voice. Students also encounter various types of text with unique language features and structures such as procedural recounts, causal explanations and persuasive discussions (Shaw, Bunch and Geaney, 2010), which have reading requirements that are distinct from requirements in other disciplines (disciplinary-specific literacies) (Shanahan, Shanahan, & Misischia, 2011). These features (hereafter referred to as the language demands of science) compound the challenges students encounter as they grapple with often abstract and non-intuitive scientific concepts and theories in diverse learning/teaching situations (teacher-directed lectures, teacher-support investigations or student-directed projects). Explicit instruction is often needed to access and master the language of science (Brown & Ryoo, 2008) for this reason.

A number of intervention studies have foregrounded the development of language use and literacy in science instruction (see, for example, studies by Fang & Schleppegrell, 2010; Fazio & Gallagner, 2019; Hand, Norton-Meier, Gunel & Akkus, 2016). Although these studies are valuable in identifying ways to develop disciplinary language and literacy abilities in science students, they do not consider the attitudes, beliefs and knowledge that teachers need to implement their instructional models successfully. As van Driel, Beijaard and Verloop (2001) aptly pointed out "reform efforts in the past have often been unsuccessful because they failed to take teachers' existing knowledge, beliefs, and attitudes into account" (p. 137). As concerns about the learning needs of English language learners (ELLs) in multilingual classrooms grow with globalisation and migration (Lan & de Oliveira, 2019; Villegas, SaizdeLaMora, Martin, & Mills, 2018), an emerging body of research is examining and identifying the language-related knowledge of content teachers (see, for example, Accurso, 2017; Andrews & Lin, 2017; He & Lin, 2018; Morton, 2018). These studies have focused on the knowledge about language that content/science teachers need to teach the language and content in science classrooms, especially to ELLs. One of the few studies to discuss the importance of KS (He & Lin, 2018) highlighted the importance of "students' interests, motivation, linguistic and cognitive abilities, individual differences as well as their sociocultural background" in the design of instruction for content and language integrated instruction (p. 183). However, their study did not systematically differentiate and characterise the nature of the aforementioned aspects of KS. We believe that a better understanding of teachers' practical knowledge for addressing language demands could inform targeted interventions and professional support for teachers in this area.

Pedagogical Content Knowledge (PCK)

PCK was first advanced by Shulman (1986, 1987) as a unique province of knowledge in teachers and is a central element of teachers' practical knowledge (van Driel, Beijaard & Verloop, 2001). In its original formulation, PCK consisted of two important components: teachers' knowledge of instructional strategies and representations; and knowledge of student learning difficulties (e.g. Alonzo & Kim, 2016; van Driel, Verloop, & de Vos, 1998). The latter component may be called knowledge of students' understanding (e.g. Magnusson et al., 1999; Park & Oliver, 2008) or knowledge of students (KS) (e.g. Author 2, 2015; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008).

PCK is widely used as a theoretical lens for studying science teachers' professional knowledge (Abell, 2007). Some scholars believe that in addition to possessing knowledge of student ideas and instructional strategies at the topic-specific level (Gess-Newsome, 2015), teachers must also possess a specialised body of knowledge about the ontological and epistemic aspects of science that support their teaching of disciplinary practices (e.g. Davis & Krajcik, 2005; de Sá Ibraim & Justi, 2019; Osborne, 2014). Such a body of knowledge, called PCK for disciplinary practices, allows teachers to "help students understand the authentic activities of a discipline, the ways knowledge is developed in a particular field, and the beliefs that represent a sophisticated understanding of how the field works" (Davis & Krajcik, 2005, p. 5). It follows that teachers also need a distinct body of knowledge to teach students disciplinary literacy, which is an important aspect of disciplinary practices.

This study focuses on the part of teachers' PCK that is related to addressing the language demands of science, a subset of teacher PCK for teaching disciplinary practices. Although it has attracted little attention in the science education community, the importance of the specialised body of knowledge for teaching disciplinary language and literacy abilities has attracted the attention of linguistic researchers. Love (2009) proposed the notion of literacy PCK (LPCK), which is relevant to the teaching of language and literacy practices in areas such as science. She conceptualised LPCK as comprising three components: '1. knowledge about how spoken and written language can be best structured for effective learning; 2. recognition that subject areas have their own characteristic language forms and hence entail distinctive literacy practices; and 3. capacity to design learning and teaching strategies that account for subject-specific literacies and language practices' (p. 541). However, her LPCK did not specifically unpack one important component of PCK: KS. This knowledge component is also missing in other knowledge frameworks designed to help teachers to address the language issues of content teaching (e.g. Bunch, 2013; Morton, 2018; Turkan, De Oliveira, Lee, & Phelps, 2014).

KS is a commonly researched component of PCK (van Driel et. al, 1998; Author 2, 2019). Different researchers have put forward different definitions of KS (see Table I in the Electronic Supplementary Materials, ESM). Together, these definitions show that KS is comprised of the following aspects: (1) students' prior knowledge (e.g. conceptions/misconceptions), (2) requirement for student learning, (3) students' learning difficulties, and (4) variations in approaches to and abilities/motivations in learning. Although Rollnick et al. (2008) included students' linguistic abilities as part of KS, they appear to be referring to the students' language background, i.e. their first language (L1) and general proficiency in the language of instruction (L2) rather than their actual linguistic performance in science (L3) (c.f. the 3-language problem identified in Yore and Treagust (2006). We argue that teaching disciplinary literacy requires KS beyond these aspects; previous PCK studies have mainly focused on teachers' KS as it relates to students' understandings of scientific concepts (i.e. conceptual aspects; see Table I in the ESM) and have tended to overlook the language demands of science (i.e. the language aspects) when they are teaching science ideas. We believe there is a need to further unpack the language aspects of KS and investigate how this dimension of KS may play out in a teacher's teaching practices as several studies of prospective teachers have cited KS as a critical limiting factor in the PCK of novice teachers (e.g. Fazio, Tarantino, & Sperandeo-Mineo, 2010). Moreover, empirical evidence suggests there are close connections between teachers' KS and their teaching practices (e.g. Author 2, 2015; Park & Chen, 2012). For example, Author 2 (2015) examined experienced teachers' PCK development in the context of teaching a new science topic and found that the teachers' KS supported the development of new instructional strategies and representations for teaching the new science topic.

In summary, these two bodies of scholarly work provide the impetus for examining KS using data collected from real classrooms. Given the close connection between teachers' KS and the use of instructional strategies and representations, another goal of this study is to delineate how KS for addressing the language demands of science inform teaching practices.

Context of study

The data for this study were generated as part of a two-stage research project to examine and enhance primary science teachers' competencies in addressing the language demands of science. The first stage (a baseline study) focused on understanding teachers' perceptions of language issues in the science classroom and examining students' work (Author 1, 2016a; 2016b). It involved collecting and examining data from teacher interviews, baseline lesson observations and student artefacts. The second stage of the study (the intervention phase) was informed by findings from the baseline study, and involved teachers working together with the first author to develop curriculum materials that addressed the language demands of a target topic. Although the intervention introduced teachers to novel methods (i.e. instructional strategies) for providing language support to students, it did not focus on teachers' KS (the aim of this study). Data collected in the intervention phase relevant to this study included recordings of lesson planning sessions, lessons and post-lesson teacher interviews.

An earlier study of the discursive practices of three teachers demonstrated the importance of KS in informing their teaching practices (Author et al., 2017). This study builds on the latter by focusing on the knowledge and teaching practices of one of the teachers in the original study, Mdm Chin (pseudonym), who was selected for the following reasons. Mdm Chin was the most experienced (six years). More importantly, she displayed the most wide-ranging KS of the three teachers and was highly reflective and articulate when discussing what she knew about her students and how that affected her teaching. Her sharing of information and opinions coupled with her insightful lessons allowed us to unpack the various aspects of her KS and associated teaching practices. Mdm Chin taught two of the four Grade 4 science classes (10 years of age, 36-39 students in each class; total: 147 students) involved in the project. As a generalist, she also taught other subjects such as English and Mathematics. These classes were conducted in a co-educational government school in Singapore, which provides six years of primary education for children. The majority of the students resided in the neighbourhood in which the school was situated, and generally came from low- to middle-income families and diverse ethnic groups (e.g. Chinese, Malay and Indian) with a small number of foreign students. The language of instruction in every subject except the Mother Tongue classes (e.g. Chinese, Malay) was English. Like all of the teachers, Mdm Chin used English as the primary language when conversing with her students and colleagues. Students learn science starting from Grade 3. English is the most frequently spoken language at home for 57% of the 5-14-year-old resident population, the age group which the classes fall into (Singapore Department of Statistics, 2015). According to the teachers in the school, students' English language proficiency spans a wide range. Hence, it is critical to provide content teachers with the knowledge and abilities they need to address the language issues in their subject matters (Bunch, 2013; Turkan, et al., 2014).

Methods

This research used an instrumental qualitative case study approach (Stake, 1995) and focused on one information-rich case. Although the generalisability of our findings is limited by this approach, they should add to the discussion of the nature and role of the theoretical construct of PCK, specifically with respect to language and literacy teaching in science. This is an exploratory case study, as most existing PCK studies focus on the conceptual demands of science learning rather than the language demands of science learning.

Data Collection and Analysis

RQ 1, which examined the nature of Mdm Chin's KS, was addressed using the data from the teacher interviews and the lesson planning sessions. Our analysis focused on Mdm Chin's "knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students" (Gess-Newsome, 2015, p. 36).

Teacher interviews. Two semi-structured individual interviews were conducted, one at the beginning and the other at the end of the year-long research project. Mdm Chin elaborated on the role of language in the teaching and learning of science, the challenges her students faced in relation to language use in science and how she addressed these challenges in the first interview conducted before the baseline lesson observations. The second interview, conducted after the lesson observations in the intervention phase, elicited her perceptions of the challenges she encountered in implementing the interventions and the students' challenges in learning about heat and temperature. Thus, the second interview provided an opportunity for her to articulate her KS related to student language demands in the context of teaching a particular topic.

Lesson planning sessions. During these sessions, the research team invited Mdm Chin to comment on the curriculum materials (i.e. lesson activities and tasks). She was asked to anticipate the content and language challenges her students would encounter when studying the topic in the first session. She was then shown the lesson activities and tasks developed by the research team and asked to suggest revisions for her students. The curriculum materials effectively elicited her pedagogical reasoning and hence her KS. The revised lesson activities and tasks, which incorporated her feedback, were the subject of discussion in the second lesson planning session. The process of discussing the interventions further revealed or confirmed her KS.

Quotations from the interviews that revealed her KS were categorised through constant comparative analysis (Strauss & Corbin, 1998). The initial generation of categories was informed by aspects of KS revealed from studies of KS from a conceptual perspective (see Table 1 in the ESM) and of the language demands on students in both general academic settings and science classrooms (e.g. Christie, 2005; Fang, 2006; Shanahan, Shanahan & Misischia, 2011). The following notions from these studies were particularly instructive: “prior knowledge”, “preconceptions”, “students’ difficulties”, “students’ variations”, “talking versus writing” and “disciplinary-specific literacies”. The constant comparative process resulted in five emergent categories that were empirically grounded and aligned with both the language demands of science and teacher knowledge fields of research.

We focused on her *teaching practices* in RQ2, particularly how her KS informed her teaching practices. Two lesson units from the two classrooms (a total of 56 lessons) were observed, recorded and transcribed during the baseline-intervention project: plant life cycles from the baseline phase, and heat and temperature from the intervention phase. As there was a more deliberate attempt by Mdm Chin to incorporate language support into her lessons on heat and temperature, the bulk of the data relevant to RQ2 came from this unit. A two-phase analysis of the lesson transcripts was conducted.

The first phase characterised Mdm Chin’s teaching practices and approaches in the overall context of the baseline-intervention project and how her teaching practices were informed by her KS. We began by examining her lessons in conjunction with those of two other teachers. We compared their main learning activities based on several observable teaching practices, including the materials and resources used (e.g. whiteboard, projector), the participation structures (e.g. individual, pair work), scaffolding and content, and text and diagrams written on the board. This analysis served to characterise their teaching practices across the classes at the macro-level (i.e. the task, activity and resource level) providing an overview of the teaching practices. However, we observed that the teachers’ talk played a more important role in addressing the language demands of science, and this required a deeper exploration. A higher resolution discourse analysis of the lesson transcripts identified utterances in which the teachers’ talk explicitly highlighted particular linguistic resources, including their form, meaning and function (Author 1 et al., 2017). This inductive micro-level analysis (i.e. at the discursive level) identified seven distinct ways in which the teachers' talk foregrounded language demands related to the topic: labelling, explaining, differentiating, selecting, constructing, deconstructing and pronouncing. This micro-level analysis also allowed us to identify the level of language (word, sentence, text) and the associated language instances attended to by the teachers.

The second phase of analysis for RQ2 involved a three-stage selection process of the relevant teaching practices. First, we identified teaching practices that fulfilled two criteria: (1) they made the linguistic features of science explicit to students, and (2) they could be distinguished from those taught by the other two teachers. The second criterion effectively eliminated teaching practices that were prescribed by the curriculum and hence uniform across the classrooms. Second, we examined how these practices were informed by Mdm Chin's KS by seeking links between the KS discussed in her interviews/lesson planning sessions and her distinctive teaching practices. Third, constant comparison (Strauss & Corbin, 1998) of the various instructional and discursive practices identified in the foregoing analysis allowed us to group the practices into four broad and distinct categories based on these criteria (see Table II in the EMS for a summary of the data and analyses).

We adopted various approaches to maximise the validity of our findings, including method and investigator triangulation (Denzin, 2017). The first phase of analysis was conducted by the first author and supported by two other coders. The analyses were conducted independently, and subsequent discussions between the coders identified and resolved any discrepancies. The second phase of analysis was conducted principally by the first author and corroborated independently by the second author. We took care to ensure that the findings from the various data sources supported and validated each other in every phase. Interview quotations and excerpts from lesson transcripts are presented to substantiate our findings.

Findings

RQ 1: Aspects of KS related to addressing the language demands of science

Mdm Chin's KS related to addressing the language demands of science have five distinguishable aspects. Two aspects are similar in nature to those identified in previous studies: knowledge of students' prior knowledge of language, and knowledge of students' areas of difficulties in language use (see Table I in the ESM). The three other aspects involved understandings of the differences in students' performance across language abilities and across subject areas and their learning progress. Interview quotations are provided to illustrate each aspect and to illuminate the extent of her knowledge. These quotations, presented in italics, have been edited slightly for readability, but retain their original meaning.

Students' prior knowledge of and about scientific language. During the lesson planning stages, Mdm Chin displayed an understanding of what her students were likely to know about particular linguistic resources before instruction. For example, she commented that the sentence starter ("*this is because*") used in association with a three-part structure (namely, observation-inference-reason) for constructing explanations was appropriate given its "*common use*" by students. She was also able to identify both the students' lack of linguistic resources and the potential challenge this presented to her students. For instance, in the lesson planning session, she highlighted one word that would likely be problematic for students: "*I'm not sure [whether] they know the word 'infer'.*" She doubted that even her Grade 5 students would be able to make sense of the word. Other words that Mdm Chin highlighted were 'results' and 'reason', for which she commented "*they are not familiar with the word "result", but "reason" is a word that they hear all the time*".

Students' difficulties with scientific language and its use. Mdm Chin's understanding of students' difficulties with language was extensive. Unlike other aspects of KS, which relate to whether students know certain words, this aspect relates to students' specific understandings of words or their use of words in a manner that is erroneous or different from scientific use. She was able to cite numerous ways in which her students had displayed difficulties with language in the past, including the use of certain everyday words instead of scientific words, which gave rise to imprecise meanings (e.g. describing the comparison of an object as "*bigger*" instead of "*having greater mass*"), inappropriate use of particular connectors (e.g. using "*then*" instead of "*but*" when setting a conditional limit), confusing cause and effect in a causal explanation, and using vague noun phrases when identifying certain referents (e.g. simply writing "*water gains heat*" without elaborating whether the water was in a basin or beaker).

In addition to pre-existing difficulties, Mdm Chin was able to foresee potential language difficulties, as evident in her attempts to anticipate limitations in her students' responses to specific tasks. For example, during a lesson planning session, when discussing a task that required students to observe that the level of coloured water in a tube would drop when submerged in a basin of cold water, she expected students to say "*the coloured water dropped*" instead of the "*the level of coloured water dropped*." She also knew that students had a tendency to represent their scientific understanding using language that she might have intended merely as an analogy to support their understanding of abstract concepts (a point elaborated further in RQ 2).

Mdm Chin was also able to provide possible explanations for these difficulties. For example, she proposed that students resisted using scientific language "*because outside of the classroom they don't use these words*." She attributed the tendency for some students to confuse cause and effect to the fact that their mother tongue reverses the cause-effect genre:

> *I think in some mother tongue language structures… the result [is stated] in front and the reason [is stated] behind [in an explanation]. [However], when we talk [in the science discipline], we tend to say the reason first, followed by the result… so that's why they [are] confused.*

In addition to the students' general language difficulties, Mdm Chin cited differences between groups of students. For example, she noted that Class 4A tended to be more responsive to oral questioning during whole-class instruction and generally performed better on science assessments than Class 4B. She added that Class 4B had "*weak comprehension skills* [and] *content issues. I think there are still things that they don't quite get*." She elaborated that their English language abilities were too weak to make sense of the content (including what the assessment items asked of them) and their understanding came mainly from pictorial aids found alongside the text.

Mdm Chin also highlighted the struggles of the weaker group of students with certain learning activities. For example, when commenting on a graphic organiser (a concept map that combined linking words between the nodes and the use of signal words and key ideas within the nodes) that was intended as a reading activity, she voiced her concerns about Class 4B by relating past experiences: "*I have tried to get them to construct their own graphic organiser. I cut [it into] pieces. They're supposed to just fit [them into] a puzzle kind of thing. [But] they can't.*" She further explained:

> *I think for many pupils an arrow is a direction or a physical line to join things, whereas in a graphic organiser, an arrow can actually have many meanings. It could be classification. It could be linkage. It could be relationships.*

This comment illustrates that she was sensitive not only to what her students could not do (graphic organiser), but also to what was the root of their difficulty (the use of arrows).

Differences in abilities across modes of language. Mdm Chin also exhibited KS in her recognition of her students' varying abilities across the different modes of language, (talking and listening versus reading and writing). She asserted that her students were better with oral than written modes:

> *They [the students] are better at listening and oral speech. [However], when it comes to reading and writing, they are weak. In general, my class is now supposed to be P4 [Grade 4], but their writing ability is about P2 [Grade 2].*

A more specific writing example is the students' difficulties using relevant nominal phrases to identify specific referents (e.g. "*the water in the bottle*" instead of simply "*the water*"). She also highlighted her Grade 4 students' preference for "*fiction[al] text*" over "*informational text*" despite being exposed to both types of text in earlier grades.

Differences in language ability across subject areas. This aspect of Mdm Chin's KS was evident when she compared her students' performance in language arts classes with their performance in science classes. She commented that students who were weak in language arts tended to also be weak in science. However, those who were strong in language arts did not necessarily perform well in science. She reasoned that not all the grammar and vocabulary skills used in language arts were applicable in science classes. She explained that the difference in performance could be partially attributed to the difference in requirements, with a higher level of precision required for language use in science. She supported this with an example:

> *Certain scientific concepts can be illustrated only by [specific] words: for example, heat transfer from a hot to a cold place. If the child wrote that the cold thing absorbs the heat from the hot thing, I would think that the child actually meant the transfer [of heat] from hot to cold. But the word 'absorb' itself has other scientific connotations. It suggests a living thing, [an] active transfer of a thing.*

This aspect appears to best capture the needs for students to not only be proficient in the language of instruction (L2) but also to master the distinctive use of linguistic resources in the discipline (L3).

Students' learning progress in language use. Mdm Chin's KS was not confined to language difficulties encountered by her students at a single point in time. For example, she was able to cite instances in which students showed signs of overcoming language difficulties : '*This year, at least for both my classes, they do try to use the word "gain heat" and "lose heat" consistently. Last year, we didn't even have that.*' Her knowledge of her students' progress was not confined to progress made by her current group of students relative to her previous cohorts. The way she adjusted her instruction as the lessons progressed (elaborated in the context of RQ2) suggested that she also monitored her current students' language performance over the lessons and was thoughtful about their trajectories in learning scientific language. For example, she ensured that her students were comfortable with the meaning of 'heat transfer' before she progressively introduced phrases such as 'heat gain' and 'heat loss'. Mdm Chin was thus cognizant of the learning progress made by both her current cohort of students across the unit of study as well as in relation to her previous cohorts.

RQ 2: Teaching practices informed by KS

Mdm Chin described and demonstrated several distinctive teaching practices that were informed by her KS. These involved (1) addressing the anticipated language difficulties her students would face, (2) adjusting her language use to students' needs, (3) differentiating her practices to cater to the needs of learners with varying language abilities and (4) questioning her students on their language use.

Addressing anticipated language difficulties. Drawing on her understanding of students' prior knowledge of language and their difficulties with language use, Mdm Chin was able to predict her students' language needs. This led her to incorporate the relevant language demands into her instruction on at least two levels. At a macro-level, her knowledge of student difficulties in language use influenced her instructional focus, as evident in her reasoning in the lesson planning session:

> *I'm able to tell you that these are all the things they couldn't do… That's why during the teaching I [will] focus on those things and explain everything in terms of heat gain and heat loss, and to emphasise that it's 'heat gained from, heat loss [to]'—the direction of flow. So, I knew these were the areas to look out for compared to last year.*

Her prior experience (i.e. her KS) allowed her to predict students' difficulties with explaining the effects of heat in terms of gain or loss, particularly the direction of flow of heat. Although the other teachers observed in this project also used demonstrations to illustrate the effects of heat, Mdm Chin's lessons were distinct for the following reasons. In explaining these phenomena, she emphasised the processes of heat loss and gain on multiple occasions throughout the unit. She also regularly wrote "*heat loss to…" and "heat gain from…*" on the white board to highlight the appropriate language for describing the process. Her understanding of this student difficulty also led her to use specific strategies to help students overcome language demands. She introduced a unidirectional wiggly arrow to represent the direction of heat transfer in numerous diagrams on the board, illustrating the mechanism that brought about the various effects of heat in different scenarios and differentiating heat flow from other graphic arrows. She maintained the use of similar phrases and diagrammatic representations when explaining the heat conductivity of different materials. In sum, her KS not only led her to identify where student would encounter difficulties and to focus on these areas whenever appropriate throughout the instructional unit, it also stimulated her to make use of relevant instructional strategies and representations (e.g. diagrammatic representations) to address those difficulties.

Mdm Chin also addressed student language demands at the micro-level, as evidenced by the whole-class discussions during which she foregrounded the language demands of science. She explained or differentiated key linguistic items. Examples of words she explicitly explained include "*electrical appliances*", "*wok*" (for cooking) and "*double-walled*" and science metalanguage terms such as "*inference".* She also differentiated between words that her students were likely to confuse, such as "*heat*" versus "*sources of heat*"; "*inflate*" versus "*expand*"; everyday versus scientific uses of "*form*"; and "*observation*" versus "*explanation*". The examples given here were unique to her classes, suggesting she did not take for granted the ease with which her students would make sense of these linguistic resources or use them in a scientifically appropriate way.

Adjusting her language use according to students' needs. Mdm Chin adjusted her instruction to suit the different stages of the lesson sequence. For instance, when her students used inappropriate words, she did not dismiss these words immediately, but instead made use of the students' established vocabulary to build their understanding until she believed they were ready to use words that were more appropriate to a scientific context. Her conscientiousness and flexibility in the area of word choice was best displayed during one of the lessons when a student responded with "*heat disappears*" when asked to explain why the temperature of an object started to decrease when a heat source was removed. In response to the student, she said, "*I think this is the best of the words you have mentioned. I would put it [referring to "heat disappears"] in inverted commas first because it's not a scientific explanation. But [I] think it will help you [to] understand.*" After she had introduced the concept of heat transfer, she urged students to replace "*heat disappears*" with a more appropriate alternative in subsequent lessons: "*Actually the right phrase to use is 'lose heat'.*" She explained why the latter phrase was preferable to "*heat disappears*": "*You put the coffee down there, and after a while, it will become cooler because the heat inside the coffee has disappeared. Now, actually it has not totally disappeared; in reality it has gone somewhere.*" She reiterated the more appropriate choice of words:

> *Now that you are a little more familiar with [heat] transfer, we need to use some proper words. We can't say 'heat disappears'; we can't say 'heat enters'. We use 'heat transfer'… Some students find 'transfer' a difficult word, so on the exam, we usually [use] 'gain heat, lose heat' [writes 'gain heat' on board].*

These exchanges demonstrated her flexibility and the balance she sought in terms of how words are used to convey scientific concepts and processes. On the one hand, Mdm Chin was aware that the use of the phrase "*heat disappears*" was inappropriate. On the other hand, she also realised that the use of established vocabulary could help her students to move forward in their understanding of what would happen when an object cooled. She delicately managed this tension by allowing students to use the unscientific phrase until she had developed the scientific concepts needed for them to transition toward more appropriate scientific explanations. She displayed a keen understanding of her students' facility with language and the transitions they need to make in moving from the everyday language (L1) to the scientific language (L3) in doing so. This flexibility suggests that she was keen to build on what her students know to achieve a common understanding.

Her careful pedagogical use of language was also reflected in the analogies she applied in class. In one lesson, she used the imagery of different animals (e.g. turtle, rabbit and cheetah) to represent the different speeds at which heat was conducted through various materials. Mindful that her students might erroneously use these pedagogical analogies in their scientific explanations, she explicitly highlighted that it was inappropriate to use these words when writing in science. She related to her students what happened to their counterparts in an upper grade when they unwittingly used language meant only as a teaching device. She told the students that she recognised their tendency to misuse her analogies and explicated the pedagogical purpose of these analogies to ensure they would not use them inappropriately. Her knowledge of her students' language use (including their tendency to use analogical language inappropriately) and their progress in language use over time enabled her to contingently respond to their language needs at different stages of the lesson sequence. It should also be noted that her use of analogies, despite her reservations, indicates a desire to build their conceptual understanding by leveraging their language skills and through examples that her students are familiar with or that resonate with the students.

Differentiating instruction to cater to the needs of learners with varying language abilities. During the pre-lesson interview, Mdm Chin described in several exchanges how she would provide more scaffolds and support for her 'weaker' students. This was certainly evident when we compared the language support she provided for the two classes she taught. The language needs of Class 4B were greater than those of Class 4A and our comparison indicated that she did indeed respond to the greater needs of Class 4B by providing more scaffolds. For example, Mdm Chin engaged in more instances of checking and unpacking the meanings of terms with Class 4B, including those not necessarily specific to science. Examples of terms unpacked in Class 4B but not in Class 4A included "*appliances*", "*goose bumps*", "*shrink*", "*remove*", "*region*", and "*double-walled*". For example, instead of taking for granted that "appliances" as a commonly used term, she explicitly checked for 4B students' understanding of the word: '*What about appliances? Does anyone have a problem with the word appliances? Appliances mean gadgets or devices or objects that help to do household work.'* In addition, she differentiated between the singular and plural forms of "*axis*" (found in graphs) and between the abridged and unabridged forms of "*laboratory*".

As many of these words were used in both classes (but not explicitly explained or differentiated in Class 4A), it was clear that she provided additional language support to the weaker class due to the students' different language abilities. Mdm Chin's awareness of the differing needs and abilities of the students in the two classes most likely contributed to the differences in her linguistic support to both classes. Occasionally, the responses provided by students in the weaker class necessitated additional intervention by Mdm Chin. In one instance, a student wrote "*The concrete expands because it does not have enough space for the concrete to fit*". The student had used the word "because" inaccurately to imply that the lack of space for the concrete was the reason rather than an outcome of the expansion of the concrete. However, despite several attempts by the teacher to get her students to identify the inaccurate use of "because" in the response, they were not able to do so. The teacher thus intervened and explained why the word "because" was used inappropriately (see Table 1 below).

Table 1. Scaffolds provided by Mdm Chin to her weaker class

Row	Speaker	Transcript
1	T	*'Not enough space for the concrete'—is that the reason why the concrete expands?*
2	Ss	*No.*
3	T	*No, right? That's it! But this sentence is written in such a way. The person is explaining that the concrete expands because there is not enough space. See the point? That means this is not a reason; this is the result. Because it expands, that's why there is not enough space… This is not the reason why it expands; this is the result after it expands. Okay, so this is a case of 'because' used in the wrong place.*

Mdm Chin's awareness of the differing needs and abilities of the students in her two classes most likely contributed to the differences in linguistic support she provided to both classes.

Questioning students on their language use. Mdm Chin's KS also influenced the nature of questions she asked in class. Table 2 illustrates how she used a sequence of linked questions to help her students develop precise descriptions in their construction of scientific explanations. Pseudonyms are used for all of the students.

Table 2. Episode illustrating the questioning by Mdm Chin

Row	Speaker	Transcript
1	T	*As Wynn correctly predicted, the water level goes up. So let's write… let's explain this using the observation, inference, reasoning structure. Okay, so let's look at the observation. How shall we describe it?*
2	John	*The water level rises.*
3	T	*Okay, you say the water level. But in this setup, there are two areas with water.*
4	S1	*Water level in the/*
5	T	*<u>/There's one in the basin, there's one in the flask, there's one in the tube. So can we be a bit more specific?</u>*
6	S1	*The water…*
7	T	*Yes, John? Can we let John try? Yes, the water level?*
8	John	*The water level in the conical flask will rise.*
9	T	*<u>Is it the flask or the tube?</u>*
10	S1	*Tube.*
11	John	*Tube, tube.*
12	T	*Good.*

She drew on her knowledge of the students' differential language abilities (i.e. students exhibited weaker writing abilities than reading abilities in the science discipline) in Turn 5 and asked further questions to help the student find the correct word. Indeed, during the lesson planning session she actually predicted that students would use the word "water" without being specific about which "water" they were referring to. She mentioned in the post-lesson interview that her students found it less difficult to read long noun phrases (especially when the text was accompanied by picture aids) than to write them. She addressed this by emphasising the importance of making referents clear and explicit. This was evident in her discourse (Turn 9) and her use of sequenced questions to explicate the referents. To summarise, because Mdm Chin recognized students' different language abilities, she used probing questions to help her students develop the ability to write scientifically.

Discussion

This case study is an attempt to dissect and illustrate how an experienced primary school teacher's KS can be used to address the language demands of science, an underexplored and under-theorised dimension of teachers' PCK for disciplinary practices. Focusing on this dimension reveals KS aspects that have not been highlighted in previous studies (see Figure 1). The language dimension in Figure 1 builds on the language background identified in Rollnick et al. (2008) by incorporating the aspects of KS identified in this study (in italics). Figure 1 thus combines both the conceptual and language dimensions to provide a more holistic perspective of KS. Although the conceptual and language dimensions differ in content, there are parallels in the nature of knowledge. Both involve prior knowledge (of preconceptions of and about scientific language), prerequisite knowledge (of scientific concepts and of language) and students' learning difficulties (with specific concepts and with scientific language and its use). The commonalities between the two dimensions of KS speak to how they are 'inextricably intertwined' (Fang & Coatoam, 2015) – the lack of language abilities invariably affects the understanding of content, and vice versa. The aspects of language KS that do not correspond with conceptual KS are 'differences in ability across language skills', 'differences in language ability across subject areas' and 'learning progress in language use over time'. The five aspects of KS have been briefly discussed in various research domains (e.g. Halliday, 2004; He & Lin, 2018). By examining KS within the framework of PCK, this study is able to examine how these aspects are manifested in the form of teachers' practical knowledge and how they inform teaching practices. These KS aspects constitute the requirements for learning scientific language and reflect the multi-faceted and complex nature of the 3-language problem that students encounter as they transit across the different discourse communities (Yore & Treagust, 2006).

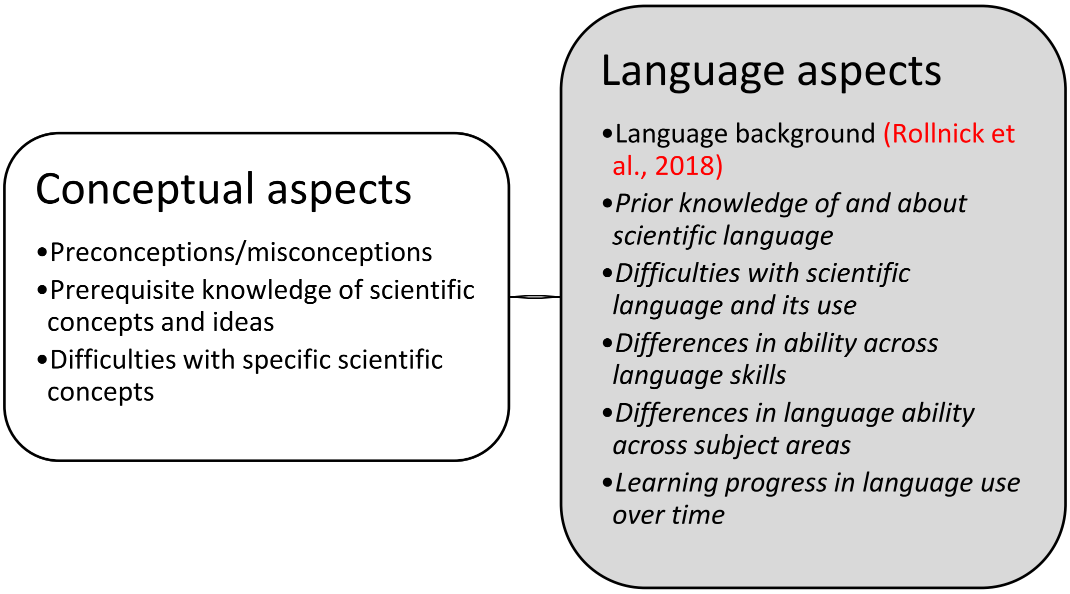

Figure 1. Conceptual and language dimensions of science teachers' KS

As language is the primary means for developing conceptual understanding, the conceptual and language dimensions of teachers' KS are equally important in developing students' understanding of science and its language. The language dimension of KS informed the actual teaching practices of our case-study teacher, particularly the way in which she adjusted her language use, questioned her students, addressed their associated learning challenges and adapted her instruction to different classes. However, we could not find clear evidence of her KS about differences in ability across subject areas shaping her instruction. We believe that to identify how she supported students' language use in different subject areas, we would have to have observed her other subjects – that is, her mathematics and English language arts lessons. Nevertheless, we speculate that her knowledge of differences in students' abilities across subject areas helped her to identify which language needs to focus on in her science classes, and what to pay less attention to, as not all language difficulties (e.g. certain syntax errors) are crucial for construing scientific meanings.

KS is not a recognised component of LPCK (Love, 2009). This study contributes to the literature by providing evidence that KS is in fact a crucial component of LPCK. Although this study situates KS within the scope of PCK for disciplinary practices, more recent and emerging research on the language-related knowledge needed by content teachers suggests that there may be grounds to consider the language dimension of KS as separate from PCK. Examples of this knowledge include Bunch's (2013) notion of pedagogical language knowledge (PLK) and Morton's (2018) language knowledge for content teaching (LKCT). Given the nascent development of this research area, there is much scope for future research on the interfaces of PCK/LPCK and PLK/LKCT and of the two dimensions of KS. Our study therefore provides a useful starting point for thinking about the content and nature of the language dimension of KS.

As this study showcases the knowledge and teaching practices of only one teacher, the findings are limited in scope. For example, the teacher's concerns for the students' language abilities tended to focus on the vocabulary they needed to interpret content knowledge and their ability to communicate established scientific knowledge in writing (that is, the communicative function of language and replicating the correctness of language use). This narrow focus could be partially attributable to the exam-driven environment (Deng & Gopinathan, 2016). This may also explain the limited consideration of the epistemic and ontological value of scientific language. Studies conducted in contexts where teachers may focus on different aspects of disciplinary literacy (e.g. a focus on the epistemic role of scientific language) and learning goals (e.g. nature of science, attitudes toward science) may reveal other ways in which KS is used to address the language demands of science. Future studies could also consider social studies or history as additional content areas, as these areas use a combination of narrative and expository genres, which may reveal other aspects of KS. Future studies could also adopt other research designs (e.g. quasi-experimental) to unpack the relationships between aspects of KS or the quality of teachers' KS and students' learning outcomes. Although there is scope for further expansion, elaboration and refinement of the identified KS aspects, this study provides a useful starting point for synthesising the various components of students' language and literacy performance that may shape disciplinary literacy teaching. The lack of such a synthesis could partially explain the limited attention paid to

KS in the teaching of disciplinary literacy. We believe that our findings pave the ways for future studies of how teacher knowledge addresses language demands.

It is also worth noting that a teacher's KS and its application could be shaped by numerous factors, including the teacher's curricular goals and how she views the role of language in science learning. The consensus model of PCK (Gess-Newsome, 2015) identifies contexts and a teacher's orientation and beliefs as important amplifiers and filters of PCK and its enactments.

Implications

In addition to theoretical contributions, our findings have several implications for methodologies for conducting research on KS and professional development programs. The case study of two classes with different student profiles provided an opportunity to examine how one teacher adjusted her instruction. Her adjustments were not principally apparent in the lesson activities and tasks, but were manifested more subtly in her explanations of terminology and in the scaffolding provided for her "weaker" class during lessons. This study empirically illustrated that observing two or more heterogeneous classes taught by the same teacher (especially those with different student profiles) can provide opportunities to examine how KS shapes a teacher's pedagogical adjustments and differentiated instruction. Moreover, our high-resolution analysis of classroom discourse, by identifying the teacher's discursive strategies and language instances, was also unique. Some previous PCK studies have examined classroom interactions (e.g. Alonzo, Kobarg, & Seidel, 2012; Author 2, 2018); however, their analytic approach does not facilitate the identification of the language demands, especially at the word level, that Mdm Chin addressed discursively. In contrast, our turn-by-turn analysis of teacher talk enabled us to identify the discursive interventions that differentiated her instruction from that of the other two teachers in our sampling frame. These interventions often involve addressing the language demands of science at the word level, which can easily be missed without such a fine-grained analysis. Our analytical approach contributes to the literature on PCK by demonstrating how we can relate teachers' discursive interventions to their KS.

Our study also has implications for teachers' professional development. It indicates the need to help teachers acquire KS focused on *both* language and conceptual demands. Although it may seem logical to consider the role of KS in the design and implementation of any research intervention, research on how to encourage teachers' ability to foster disciplinary literacy has tended to focus more on their knowledge of integrating language and literacy in science instruction (i.e. teaching strategies and/or instructional approaches), with a generic call for attention to students' backgrounds e.g. home languages and cultures (Hart & Lee, 2003). However, for teachers to effectively execute the strategies taught in their interventions, they must also adapt these strategies to suit their students' emerging and evolving language needs within the classroom contexts, which goes beyond the general linguistic background of students.

To achieve such goals, it is important for professional development efforts to explicitly highlight the existence and utility of the various KS aspects identified in this study and to encourage teachers to constantly develop their KS. This would prevent teachers from making premature evaluations of their students and ensure that they can adjust their pedagogy to students' specific and evolving language needs. The examples presented in this study demonstrate the importance of making these KS aspects explicit, and may encourage teachers to reflect on those aspects and pay greater attention to students' language use in class. This would be especially important for pre-service teachers who often lack the practical experience that would allow them to observe and reflect on their students' use of language. Although in-service teachers may have more awareness of their students' struggles with language, they will not necessarily always appreciate the nature and extent of the interrelationships and interdependencies between language learning and conceptual understanding. In addition to enhancing teachers' awareness of KS, teachers' abilities to develop or adopt formative assessment tools that reveal students' performance should be enhanced. Educative curriculum materials (Davis & Krajcik, 2005) could also be designed to incorporate prompts to help teachers to collect relevant information from students on the various KS aspects. Although a strong KS alone would not be sufficient for teachers to respond to students' language needs, it is our hope that this awareness will motivate teachers to seek out the resources and professional development opportunities that will provide them with the necessary instructional strategies or approaches.

Notes

[1] Disciplinary literacy in this study refers to 'the ability to engage in social, semiotic, and cognitive practices consistent with those of content experts' (Fang, 2012, p. 19).
[2] Language abilities refer to the capacities to engage in the various language modes such as speaking, listening, reading and talking, specifically in English, the language of instruction for science lessons in the context of this study.

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Electronic Supplementary Materials (ESM)

Table 1. Nature of Knowledge of Students (KS)

Authors	Knowledge of Students
Shulman (1986, pp. 9-10)	The conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.
Magnusson, Krajcik, & Borko (1999, p. 104)	Requirements for learning specific science concepts and areas of science that students find difficult.
Lee, Brown, Luft, & Roehrig (2007, p. 54)	Students' prior knowledge, variations in students' approaches to learning, difficulties with specific science concepts.
Park & Oliver (2008, p. 266)	Students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need.
Rollnick, et al. (2008, p. 1381)	Students' prior knowledge, how they learn, their linguistic abilities and interests and aspirations.
Gess-Newsome (2015, p. 32)	Incoming student knowledge or misconceptions.

Table 2. Data used in the analyses

Research question	Data sources	Analysis
RQ1	Two semi-structured teacher interviews Two lesson planning sessions	Constant comparative analysis
RQ2	56 lessons from two lesson units	Phase 1: Characterise Mdm Chin's teaching practices Level 1: In terms of main learning activities Level 2: In terms of her discursive strategies Phase 2: Identify Mdm Chin's distinctive teaching practices <u>Stage 1</u> Identify teaching practices that fulfil two criteria: (1) explicit focus on linguistic features of science; and (2) not found in the other teachers ↓ <u>Stage 2</u> Search for links between KS and teaching practices identified in Stage 1 ↓ <u>Stage 3</u> Group the KS-linked instructional and discursive strategies into four broad practices using constant comparison