International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

The roles of teachers' science talk in revealing language demands within diverse elementary school classrooms: a study of teaching heat and temperature in Singapore

Lay Hoon Seah & Larry D. Yore

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
http://dx.doi.org/10.1080/09500693.2016.1270477

The roles of teachers' science talk in revealing language demands within diverse elementary school classrooms: a study of teaching heat and temperature in Singapore

Lay Hoon Seah[a] and Larry D. Yore[b]

[a]Learning Sciences Lab, National Institute of Education, Nanyang Technological University, Singapore; [b]Faculty of Education, University of Victoria, Victoria, Canada

ABSTRACT

This study of three science teachers' lessons on heat and temperature seeks to characterise classroom talk that highlighted the ways language is used and to examine the nature of the language demands revealed in constructing, negotiating, arguing and communicating science ideas. The transcripts from the entire instructional units for these teachers' four culturally and linguistically diverse Grade 4 classes (10 years old) with English as the language of instruction constitute the data for this investigation. Analysis of these transcripts focused on teachers' talk that made explicit reference to the form or function of the language of science and led to the inductive development of the 'Attending to Language Demands in Science' analytical framework. This framework in turn revealed that the major foregrounding purposes of teachers' talk include labelling, explaining, differentiating, selecting and constructing. Further classification of the instances within these categories revealed the extensive and contextualised nature of the language demands. The results challenge the conventional assumption that basic literacy skills dominate over disciplinary literacy skills in primary school science. Potential uses of the analytical framework that could further expand our understanding of the forms, functions and demands of language used in elementary school science are also discussed.

ARTICLE HISTORY
Received 8 April 2016
Accepted 6 December 2016

KEYWORDS
Disciplinary literacy; language demands; language functions; teacher talk

Introduction

The fundamental roles of language in science have been widely recognised over the past decades: communicative, epistemic and persuasive functions (Carlsen, 2007; Yore, 2012) and encapsulated in notions such as fundamental literacy (Norris & Phillips, 2003), disciplinary literacy (Moje, 2007), enterprise language (metalanguage, Shananhan, 2012) and science literacy for all (Yore, 2012). Underlying these notions is the recognition that scientific language differs from the language used in other school disciplines and in everyday life (Gee, 2004; Yore & Treagust, 2006). The distinctive linguistic features,

CONTACT Lay Hoon Seah layhoon.seah@nie.edu.sg Learning Sciences Lab, National Institute of Education, 1 Nanyang Walk, Singapore 637616
Supplemental data for this article can be accessed http://dx.doi.org/10.1080/09500693.2016.1270477.

norms, conventions, genres and structures that characterise scientific language have been identified by Systemic Functional Linguistics (SFL, Halliday, 2004). Studies that highlighted students' difficulties in interpreting and employing language used in science further indicated that besides conceptual demands, science learning also imposes considerable general and discipline-specific language demands on students (e.g. Frändberg, Lincoln, & Wallin, 2013; Seah, Clarke, & Hart, 2014).

A continuing critical aspect of science teaching involves attending to and addressing the purposes and demands inherent in the use of everyday, academic and science languages within instructional approaches and learning environments. Despite the important roles that language plays in the teaching and learning of science, little is known about teachers' awareness of the language demands and how teachers attend to these demands in culturally and linguistically diverse science classrooms (Braden, Wassell, Scantlebury, & Grover, 2016; Gonzalez-Howard & McNeill, 2016). Science teachers are generally perceived as not giving due attention to the teaching of language and literacy in science classrooms, while language and literacy teachers do not give due attention to the unique language attributes of specific disciplines like science (Wellington & Osborne, 2001). Therefore, this study of diverse Grade 4 science classrooms seeks to examine the validity of such perceptions, by examining three teachers' talk that foregrounds (*a discursive act that indicates linguistic prominence, emphasis and priority that supports students in their engagement, use or performance of language tasks)* the language demands of science.

Background

Classroom discourse ('spoken or written text intended to accomplish social ends of language users within specific contexts and constraints'; Grimshaw, 2003, p. 27) is a significant means by which both teachers and students engage in meaning-making (Kelly, 2007, 2014). Teachers attempt to explicate the distinctive features, norms and conventions of the language of science and to disseminate information (communicative function), construct understandings (epistemic function) and argue and justify knowledge claims (rhetorical or persuasive function). This study focused on teacher talk (spoken discourse) in diverse Grade 4 classrooms near the beginning of the students' formal science instruction. While research on promoting the use of language in science is growing in recent years (Fang, 2012a; Moje, 2007), studies on how teachers attended to the language demands of science at the discursive level are scarce. The scarcity of such research is perhaps due to the perception that science educators are generally resistant to language and literacy instruction and language and literacy educators lack insights into the nature of science and the epistemological, ontological and metalanguage attributes of authentic science.

Understanding the beliefs and practices of teachers can serve to better inform the design of interventions that seek to promote the learning of scientific language and learning science through language, address the needs of culturally and linguistically diverse students, and narrow the theory–practice gap between research recommendations and classroom interventions (Greeno & Collins, 2008; Seah, 2016a; Windschitl, 2002).

Theoretical perspectives

This study is underpinned by two theoretical perspectives – socioconstructivist and sociosemiotic – involved in the use of and transition amongst daily language, school language and science language (Yore & Treagust, 2006). This three-language problem can be exacerbated by the challenges between learning language and using language to learn, often called the Grade 4 slump, in which students encounter more complex language, informational genres and abstract concepts (e.g. the transition of learning to read and reading to learn from printed texts). The socioconstructivist perspective (Vygotsky, 1986), which emphasises the roles of language as both instruments of social interactions (cultural tool) and verbal thought (cognitive tool) within an individual, provides the basis for analysing the teachers' talk. As a science teacher engages students through interactive whole-class discourse, a process of social enculturation takes place. The students internalise the cultural tool (the language of school science) at the social plane and then employ it at the intrapersonal plane as a cognitive tool to construct and represent personal meaning (Mortimer & Scott, 2003).

The sociosemiotic perspective identifies language as semiotic (meaning-making or epistemic) resources, which is realised through the lexicogrammar (Halliday, 2004). Lexicogrammar, comprised of syntax, morphology and vocabulary, serves as a representational tool and helps to determine our perceptions of the world by imposing categories and relationships on them. Halliday (1993, p. 113) proposed a three-fold perspective of learning: 'learning language, learning through language, learning about language'. Learning language in diverse classrooms involves both learning the language of instruction (in this case English) and the language of the discipline (in this case science) to negotiate, communicate and argue about ideas considered in the learning experiences. Learning science through language involves constructing science understanding using these languages. Learning about English and science language involves the elements, parts, conventions and traditions of these languages. It is important to note that these processes of learning can occur concurrently (albeit to different extent) since language construes content and the two are inextricably intertwined. The process of learning science entails not only learning science *through* language but also the learning *of* and *about* the language of science simultaneously, albeit not necessarily at a conscious level. In diverse classrooms, it also involves English language learners (ELL) learning about everyday and academic English. Lee and Luykx (2007) stated, 'All too often, teachers' knowledge of science and/or student diversity is insufficient to guide student from diverse backgrounds toward meaningful science learning' (p. 171). They suggested that if the language needs of ELL are not successfully addressed, these students are frequently faced with lower achievement in science and other subjects. Buxton and Lee (2014) stated, 'students will need to engage with the full range of oral and written communication skills in new and challenging ways' (p. 206), which will include a variety of talking–listening, writing–reading and representing–viewing tasks in the complex transition embedded in learning and teaching science. Yore and Treagust (2006) outlined the three-language problem (home – L1, school – L2, discipline-specific languages – L3) to conceptualise the differences in language and communicative, epistemic and rhetoric functions of language in doing and learning science. These distinctive but intertwined processes of language and learning could explain why students encounter varied difficulties with respect to science learning. For instance, some students may have little difficulty understanding science concepts (as evident from other semiotic tools such as drawing) but may be less competent with expressing their understanding verbally (Schoultz, Säljö, & Wyndhamn, 2001). Both socioconstructivist and sociosemiotic perspectives provide the theoretical basis for characterising teachers' talk that foregrounds the learning of and about the language of science – conceptual terminology, expository genre and enterprise terms (metalanguage) – while ELL students learn also about English.

Scientific language and literacy progression

Studies utilising SFL framework have examined the language of science as employed in scientific texts (Halliday, 2004), school science textbooks (Fang, 2005; Unsworth, 2001) and students' writings (Christie & Derewianka, 2008) to unpack its distinctive features at different levels. At the lexicogrammatical level, where the language demands relate to the use of individual lexical and grammatical items, scientific language is characterised by its vast specialist vocabulary, the use of grammatical metaphors (including nominalisations) and the unique use of other grammatical items such as prepositions, conjunctions and pronouns (Fang, 2005). These lexicogrammatical resources are then put together in ways that fulfil the linguistic norms and requirements of various science genres (Unsworth, 2001). The ability to recognise the differences between oral and written language (e.g. the use of endophoric and exophoric references – the former refer to 'references to things outside the language and in the context', whereas the latter refer to those 'that build coherence within the text', Christie, 2005, p. 51) is also an important aspect of learning to use the language of science (Seah, 2016b) and so is the differences between everyday and other disciplinary languages and the language of science (e.g. different lexical density and active versus passive voice, Fang, 2005; Schleppegrell, 2004). While recent studies on the distinctiveness of scientific language have focused mainly on scientific writings, less research has addressed similar issues in oral constructive–interpretative discourse (talking–listening, Tippett, 2011) within interactive–constructive learning environments. These language features provide possible dimensions for characterising the nature of the language demands that teachers attended to or initiated in their talk as they address learners' needs and abilities and disciplinary goals of specific science topics.

Shanahan and Shanahan (2008) proposed a pyramidal representation for literacy progression distinguishing between basic, intermediate and disciplinary literacies. They suggest that the bulk of what students master at the elementary grade levels (i.e. the base of the pyramid) are basic literacy skills that are widely applicable across all or most disciplines, 'such as unpacking and knowledge of high-frequency words that underlie virtually all reading tasks' (p. 44). Transiting between the elementary to high school levels, students progressively add to their basic repertoires more sophisticated but narrowly applicable literacy skills, such as 'generic comprehension strategies, common word meanings, and basic fluency', which are not 'particularly linked to disciplinary specializations' (p. 44). The peak of the pyramid represents the disciplinary literacy skills expected of high school students that are highly specialised and sophisticated. One interpretation of the pyramid representation implies that students progressively learn these basic, intermediate and disciplinary literacy outcomes with experience and instruction. However, other scholars have argued that these discipline-specific literacy skills can be achieved by younger students who are provided explicit disciplinary literacy instruction (Fang & Coatoam, 2013). These conflicting views on the placement of disciplinary literacy instruction bear scrutiny.

The following research questions guided the design and enactment of this study:

> RQ#1: How did the teachers' talk foreground the language demands in the topic heat and temperature?

> RQ#2: What are the characteristics of the language demands that were addressed through the teacher–student interactions?

Design

This research used an integrated discourse analytic study of three elementary school teachers' instruction and the associated language demands in teaching Grade 4 students about heat and temperature. The interpretive analysis took into account not just the talk itself but also the contexts in which the talk occurred (e.g. as part of a demonstration, use of other media such as PowerPoint slides) and the accompanying contextualisation cues (e.g. gestures, laughter).

Context of study

The data for this study were generated as part of a yearlong research project that sought to examine and address the language challenges encountered by students in four culturally and linguistically diverse primary science classrooms taught by three teachers. The host school for this project was a co-educational government school in Singapore that provides six years of primary (Grades 1–6) education for children; the majority of the students reside in the working-class neighbourhood where the school is situated. English is the main language of instruction for all subjects, except during Mother Tongue lessons (e.g. Chinese, Malay and Tamil). A recent Singapore census indicates that English is the most frequently (50.5%) spoken language at home in the age group 5–9-year-old resident population, while the home language of the remaining 49.5% of this target population speaks mainly mother tongues (Department of Statistics, 2011).

Students begin their formal science instruction at Grade 3 (age 9 years) and sit for a national examination at the end of their primary education (i.e. Grade 6). Therefore, Grade 4 represents an early stage in these students formal science education. Students in past cohorts from this school have generally performed below national average in the national examination.

A total of four Grade 4 classes (around 10 years of age) with 36–39 students each (total: 147 students) participated in this study. The students were of different ethnicities (e.g. Chinese, Malay and Indian) with small minorities born overseas (mainly Asian countries). All participants provided written consent for involvement in this study, including the parents of the students as required by the university's research ethics approval process. The three participating teachers varied in their teaching experiences with the most experienced teacher among them teaching two of the classes.

The heat and temperature unit was conducted over a range of 9–10 weeks and comprised between 19 and 24 lessons (a total of 83 video-recorded lessons). Each lesson typically spanned between 35 and 70 minutes depending on whether it was a single- or doubleperiod lesson. A typical lesson followed a semi-structured inquiry approach with an introduction to establish lesson focus and access, engage and challenge students' prior knowledge and ideas (5–10 minutes), an experience related to the lesson focus (10–20 minutes), and whole-class discussion to consider the new experiences and confirm or construct new understandings (15–30 minutes) followed by some type of formative assessment of learning (5–10 minutes). Whole-class discussion dominated the lessons in all four classes, aimed towards fulfilling the following instructional goals: common sources of heat, differentiate between heat (form of energy) and temperature (measure of hotness), heat flows from hotter to colder objects until they reach the same temperature, effects of gain or loss of heat (i.e. change in temperature/states and expansion/contraction) (Ministry of Education, 2007). These objectives, which the teachers referred to as the intended curriculum, determine what was to be taught and the sequence of lessons generally followed the order of the objectives as stated in the syllabus.

The effects of heat were illustrated with a variety of demonstrations (e.g. a ball-and-ring experiment, effect of hot water on raw egg) during which the teachers engaged in a typical IRE triadic dialogue (initiate-response-evaluate) with the students, – in which the students responded to the questions posed by the teacher who then extended the dialogue with typically an evaluative comment followed by further questioning (Lemke, 1990). The students learnt how the temperature of objects can be measured and used a laboratory thermometer, while the teacher demonstrated a data logger attached to a temperature sensor. The students were engaged in a variety of writing tasks, which include the student workbook and assessment book; teacher-made resources; and researcher-made materials.

Data

This study focused primarily on the 83 video records of the instructional sequences from the four classes. A single video camera synced to a wireless microphone that the teacher clipped on was placed at the back of the classroom to record the lessons over a complete unit. The analysis of the sets of Grade 4 lessons allowed the different facets of the language demands at different stages of learning to be investigated. The videos related to heat and temperature (a few lessons involved topics outside the target unit) were transcribed verbatim, which served as the data for this study.

Data interpretation and interpretative framework

Unfortunately, an established framework for capturing and interpreting foregrounding in teachers' talk that focused on the language demands in elementary school science instruction could not be found. Therefore, it was necessary to develop such a framework empirically from the data and the theoretical foundations to provide such an analytical tool for this study. A three-phase discourse analytic method was adopted to analyse the transcripts and inductively generate an interpretative framework that could be used in the final round of data analysis.

Phase 1: selection of utterances for analysis

The first phase involved open coding to generate broad descriptors about the role of the talk and the nature of language demands. Open coding was conducted on all the transcripts from one class – considered to have the most variety of teacher talk among the classes – comprising 24 lessons and 9049 speaker turns. This phase was conducted by the first author and a research assistant with a Master's degree in linguistics, and led to the refinement of the criteria for selecting talk that foregrounded language.

Teachers' talk in science instruction can have multiple affordances/goals at any point of time, but at different times, certain aspects are foregrounded. The switch in emphases and intentions can be detected as a teacher engages in a discussion with students to build a science narrative; the focus may shift depending on the needs of students at different points from learning science through language to learning the different aspects of the language that would empower the students to make sense of the language itself. It is those points where the emphasis is on learning the aspects of the language that the language demands of learning science is said to be 'foregrounded'. Hence, only teachers' utterances that made explicit reference to the form or function of language were considered.

The unit of analysis was the part of utterance that focused on and highlighted a particular aspect of a linguistic item. A unit of analysis might comprise one or a series of continuous statements. Each unit of analysis has to meet two criteria: (1) a particular linguistic item was highlighted by another part of the speech that calls attention to this item itself (explicit reference) and (2) a particular aspect of the identified linguistic item involving either its form, meaning or type was talked about (elaborated the identities). The following non-example and example illustrate how the selection was made:

Non-example:

T2: Heat flows from the fire.

Example:

T1: So heat is different from the fire because the fire is the one that produces the heat. Ok, so these 2 are different [pointing to the board]. This is the one [point to 'heat'] that is causing the changes [point to 'temperature increase']. The fire is not the one causing the change. The fire produces heat, the heat cause the change.

Only the example satisfied the condition of 'explicit reference' as the teacher highlighted 'heat' and 'fire' through speech and gestures and simultaneously 'identified the identities', which is that the two terms are different in meaning. In contrast, the non-example does not explicitly indicate the difference between the two terms, but only implied the difference. Although it was possible to derive from the first utterance that 'heat' is different from 'fire', the utterance itself was not considered as foregrounding the language demands specifically. Therefore, the first statement was not selected for coding as an example of foregrounding. It is worth noting that the example promotes not only the learning about (the distinctiveness of 'fire' and 'heat') language, but it also promotes the learning of the conceptual relationships (cause–effect) between the different concepts through language, while the non-example focused mainly on the causal relationship.

The data generated from these lessons were rich with instances of teacher talk that foregrounded the language demands of science. The rich dataset allowed for a comprehensive understanding of the range of ways in which this teacher indicates linguistic prominence, emphasis and priority that supports students in their engagement, use or performance in language tasks.

Phase 2: developing the functional categories of the Attending to Language Demands in Science framework

The second phase involved developing the 'Attending to Language Demands in Science (ALDIS) Analytical Framework' using constant comparison (Glaser, 1992) of this initial set of descriptors and guided by the first research question (How did the teachers' talk foreground the language demands in the topic of heat and temperature?). The first author generated a set of core categories that could capture the wide range of descriptors identified in the first round of open coding. After the preliminary framework was proposed, the two coders met, shared and deliberated their clusters of teacher talk to address discrepancies and establish consensus categories, which were used to reanalyse the initial lessons to verify the categorical demands, identify missed examples and elaborate the teacher talk within each category.

With the set of categories generated from the first class, the two coders proceeded to analyse the transcripts from the other three classes. Special effort was made to ensure that instances that did not fall into the initial set of core categories were not dismissed but coded as miscellaneous. Discussions among the coders identified and resolved discrepancies. A recursive approach with constant refinement and addition of categories was thus used to generate a stable set of categories that are applicable across the entire dataset. The first author, the initial coder and one more coder (a former trained teacher familiar with the dataset) reanalysed around 40% of the transcripts using this final set of categories. Once a high level of consistency (more than 90%) in the use of the categories was established (Figure 1), the first author and the initial coder shared the coding of the remaining 60% of the transcripts.

This first set of categories, which we named as functional categories, classify the talk according to the various ways in which the talk foregrounded the language demands related to the topic, such as through labelling, explaining, differentiating, selecting and constructing. These categories will be described and exemplified in the findings section.

Phase 3: Characterising the instances identified using the ALDIS framework

The second research question (What are the characteristics of the language demands that were addressed?) was addressed by subjecting the identified instances within each category to further analysis informed by the literature on the specialised language features of science and classroom discourse analysis literature (e.g. Fang, 2005; Halliday, 2004; Walsh, 2006; Wellington & Osborne, 2001). Across the categories, the instances can be characterised in two dimensions: level and aspect of language. The level of language refers to the structural composition of the linguistic item, that is, whether it is a word/phrase, a general sentence, or a particular type of text (which could comprise one or more sentences that serve a particular linguistic function, for example, an answer to a particular question, an observation or an explanation). The aspect of language refers to whether it is the language form, meaning, type or the interconnection between two or more of these aspects that was the focus of the talk (e.g. 'labelling' focuses on the form of language, 'explaining' focuses on the meaning, while 'differentiating' could be on the form, meaning or type). The form of a linguistic item refers to its expression and physical attributes, including its spelling, pronunciation and so on. The meaning refers to what the linguistic item represents, that is, its linguistic content. The type of a linguistic item varies depending on the level of language. Different types of words/phrases refer to the different

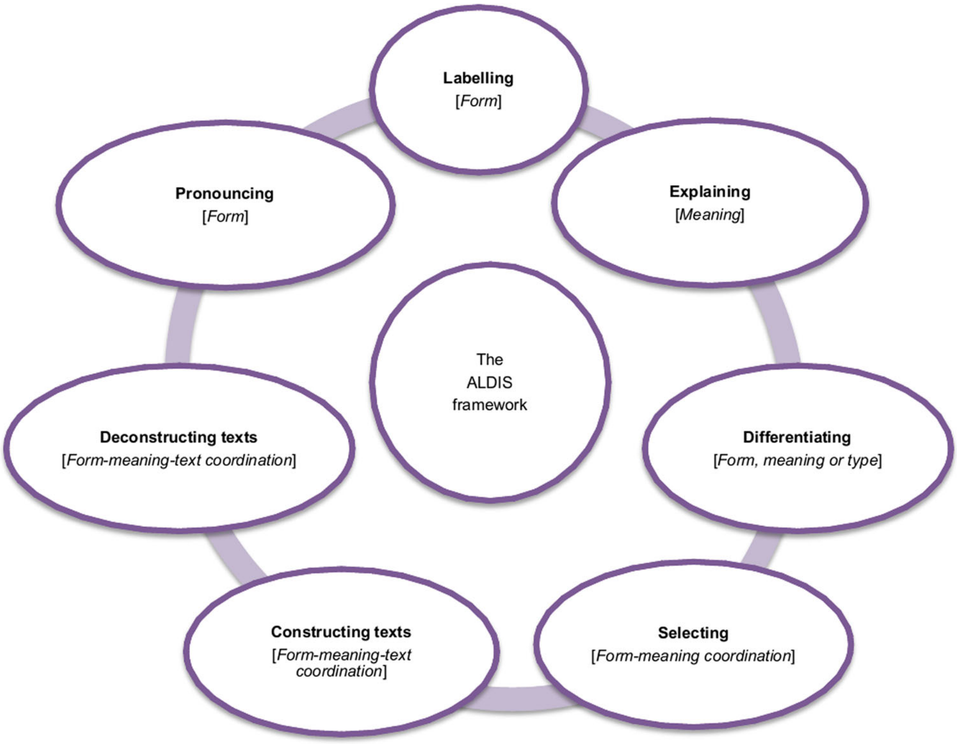

Figure 1. The functional categories in the ALDIS framework.

word classes that they belong to such as noun, verb and adjective. Different types of texts refer to texts with different linguistic function (e.g. prediction, observation, explanation). For example, within the functional category of 'differentiating', the linguistic items being differentiated in this study are of two levels: words/phrases and texts, which could be either their form (e.g. word form such as singular versus plural), meaning (e.g. word meaning such as everyday versus scientific meaning) or type (e.g. word type such as comparative adjective versus connector).

Besides the level and aspect of language, separate analysis of the instances within each functional category was conducted to further illuminate the specific nature of the language demands addressed by the teachers and to add subcategories (e.g. scientific terms, academic terms, everyday terms). The data interpretation procedures, functional categories and subcategories constitute the ALDIS framework used to reveal and characterise the nature of the language demands in the talk. When reporting the findings, some references are made to when the talk occurred within the instructional timeline to provide a general sense of how the language of the topic evolved over time.

Findings

The analysis uncovered a total of seven explicit ways in which the teachers highlighted the language demands of science – **labelling, explaining, differentiating, selecting, constructing, deconstructing** and **pronouncing**. These functional categories reveal the roles of the oral language in these science classrooms – the need for teachers to first establish the semiotic resources for learning science before concept formation, concept attainment and the interplay between the two can be addressed. The functional categories (**boldface**) that make language prominent or explicit are illustrated by using representative quotes from teachers (*italics*), which might be contextualised by visual or situational information (normal type). The teachers' quotations have been edited slightly to aid readability and logical flow while retaining the intended meaning. These functional categories brought the various language demands of heat and temperature to the Grade 4 students' attention.

Labelling

Labelling involved the introduction of a word or phrase (form) as a sign for a specific entity or phenomenon. During the **labelling** process, the teachers attached a specific term to a particular object, idea, process, representation or concept in a deliberate and explicit manner. The form of the linguistic items was the focus in this process, with all the instances at the level of words or phrases.

> T1: Now these thermometers were used in the laboratory, so we call them laboratory thermometers.

> T1: Maybe I should ask this class first – Do you know what is the white thing? [referring to the semi-transparent liquid from a cracked egg]

These two examples of a teacher's talk illustrate the typical process of **labelling**. The **labelling** process occurred throughout the entire lesson sequence, but was particularly pervasive whenever a new experimental activity that involved new apparatus was introduced. The purpose of the **labelling** process appeared to ensure a shared understanding of the associated referents (laboratory thermometer, semi-transparent liquid in an egg, etc.) being talked about, and has the added effect of expanding the students' vocabulary repertoire and establishing the basic understanding with the paired association of the object, idea, event or representation and the assigned label (concept formation that might serve as the anchor for deeper understanding of the critical attributes leading to concept attainment).

Further understanding of this category's origin can be achieved by classifying the labelling instances according to the contexts in which the students were likely to encounter them. The subcategories include everyday terms (language often used in everyday life), academic terms (language used more commonly in educational settings) and scientific terms (language used mainly in science). Scientific terms can be further sub-divided into topic-specific terms (e.g. 'thermometer', 'contraction', 'radiation') related to heat and temperature and those that are domain-general terms (e.g. 'Bunsen Burner', 'hypothesis') related to several science topics/disciplines and the scientific enterprise (scientific metalanguage). Table 1 illustrates the words/phrases documented in the teacher talk for each of these subcategories (Appendix A provides a more comprehensive listing). The majority (77.6%) of the instances (45 of 58 distinct instances) could be considered as discipline-specific vocabulary that the students would need to appropriate for the learning of science. Among these 45 scientific terms, more of them were topic-specific (28 instances)

Table 1. Some instances found within the functional category of **labelling**.

Type of instance	Instances
Scientific term: topic-specific (heat and temperature)	Bulb; clinical thermometer; digital thermometer; good/poor conductor of heat; degree Celsius
Scientific term: domain-general	Glass tubing; conical flask; data logger; effects; variables; prediction; hypothesis
Academic term	Graphic organiser; horizontal axis
Everyday term	Egg white; sweater; gaps; pop up

than domain-general (17 instances). The remaining instances ranged from everyday terms (10) to academic terms (3) applicable to other disciplines.

Explaining

Not surprisingly, much of the classroom talk that explicitly addressed the language demands involved the teachers' attempts to illuminate and clarify the meaning of particular linguistic items (scientific terms, academic terms, everyday terms) that were essential to bring about a shared understanding with both the English-proficient and ELL students. The **explaining** category involved the process of attributing a particular meaning to a linguistic item. While much of science classroom talk would involve unpacking the meaning of scientific ideas, the bulk of the defining, elaborating and clarifying occurs implicitly as teachers describe and explain a scientific phenomenon. Unlike such talk, the **explaining** instances identified refer to those utterances where the teachers emphatically highlighted a particular linguistic item for explication. Table 2 shows some of instances that have been explicitly defined or explained during the lessons (Appendix B provides a more comprehensive listing).

The **explaining** function works with the **labelling** function to provide examples that define or clarify an object, event, representation or idea and thereby the same entries can be the focus of both categories. The language that was explained ranges from a word/phrase, a particular sentence to a particular text. Among the words/phrases, 64% of the 100 distinct instances identified are scientific terminologies that could be topic-specific (36 heat & temperature terms) or domain-general (28 scientific apparatus, procedures, processes, practices or enterprise terms). The rest of the words/phases are either academic English (14) or everyday English terms (22).

Table 2. Some instances found within the functional category of **explaining**.

Type of instance		Terms that were explained	Examples of meaning provided by teachers (*italics*)
Scientific word/ phrase	Topic-specific heat & temperature	Heat; source of heat; temperature	Heat: *a form of energy that makes things hot.*
	Domain-general	Apparatus; form; type	Define: To state or describe clearly
Word/phrase	Academic	Analogy; axes; graphic organiser; verb	Verb: *action words*
Word/phrase	Everyday	Appliances; brief; circle back	Inflate: *to fill with air*
Sentence		A particular sentence in the practical worksheet, textbook; student's statement	[T would highlight a sentence and read it aloud, taking time to address difficult terms and structures]
Text		A particular paragraph in the textbooks; text on a PowerPoint slide	[T would typically highlight particular paragraph in the text and then proceeded to paraphrase it.]

Explaining, like labelling, can either be provided by the teachers themselves or elicited from the students depending on the likelihood of their prior experience, knowledge and understanding and the specific teaching approach as shown below.

T1: What do you mean by 'define'? Define means to state or describe clearly.

T1: What do you understand by the word 'produce'?

The involvement of the students often served as a means by which the teachers checked their understanding to ensure that they could recall or were familiar with the language. The **explaining** process was especially prevalent in the introductory lessons (particularly those involving individual words/phrases) and tapered off towards the latter half of the instructional sequence when higher level cognitive tasks and demands were required.

Differentiating

Another means of foregrounding the language demands involved **differentiating** words/phrases or texts in terms of their form, meaning or type. The teachers distinguished between pairs of linguistic items (compare/contrast) with the aim of bringing about greater clarity of the language that could be misunderstood, unclear or confusing to the students. The **differentiating** process occurred throughout the entire instructional sequence but tended to follow labelling and explaining of the associated linguistic items. Table 3 provides subclassification of some instances that reveal the basis of the difference between the contrasted pair of linguistic items to better understand the need for their differentiation (Appendix C provides a more comprehensive listing).

The first five subcategories have to do with the semantics (meaning of a word or phrase). The first subcategory involved differentiating between concepts. Explicit differentiation between concept words appeared closely tied to the content objectives and occurred mainly during the introduction of the concepts. This process highlights their nature and scope, thereby reinforcing the meanings of the concepts. Occasionally, the cause–effect relationships between the terms were explicated. The second subcategory involved contrast between referents such as *flask with air* (referent: flask) versus *air in flask* (referent: air). The last three subcategories involved distinguishing between synonyms, antonyms and homonyms.

Another cluster of subcategories involved differentiation according to the type or form of the words/phrases. On one occasion, the students provided examples of logical connectives ('while', 'therefore', 'however') instead of comparative adjectives as requested by the teacher. This provided the teacher with the foregrounding opportunity to differentiate between the two word-types (logical connective, comparative adjective) in terms of their functions across disciplinary and social conversations. Differentiating word forms involved contrasting the different manifestations of a word that arose out of its use in different linguistic contexts (e.g. 'expansion' employed as a noun and 'expand' employed as a verb), whether they are plural or singular form, abbreviation of the long form, the root word versus derived form and the present versus past tense. A total of 30 distinct words/phrases were differentiated, with 19 being scientific words/phrases, 5 being academic words/phrases, and 6 being everyday word/phrases.

Table 3. Some instances found within the functional category of **differentiating**.

Type of instance		Illustrating transcript	Instances
Different concept words		T1: *Temperature is the result, heat is the cause.*	'heat' vs. 'temperature'
Different referents		T3: *Flask with air and air in the flask are two different meanings. When I say air in the flask, I'm talking about the air, whereas when you say the flask with air, you're telling about the flask rather than the air.*	'flask with air' vs. 'air in flask'
Synonyms		T1: *Inflate is not the same as expand. Inflate just means, filled with?*	'inflate' vs. 'expand'
Antonyms		T2: *… know that conductor and insulator are opposites, these are your antonyms.*	'an insulator' vs. 'a conductor'
Homonyms		T1: *So form here is not the form that you fill up, ok. Here it means a type or a kind.*	'form' (everyday vs. scientific)
Different word-types	Comparative adjectives vs. logical connectives	T1: *Therefore is a connector. Therefore is more for result. Because of this, something happen.*	'while', 'therefore', are logical connectives not comparative adjectives
Different word forms	Verb vs. noun	T2: *Which is the noun? The noun is expansion, because … you can say something like this: the expansion of something. To expand is the what?* [S responds] *Verb. Very good. Expand is doing something.*	'expansion' vs. 'expand'
	Plural/ singular forms	T1: *So a graph will have two axes, what we call axes. Singular: axis, plural* – [teacher writes 'axes' on a paper on the projector].	'axis/axes';
	Origin of linguistic resources	T1: *The other effect we'll look at is expansion and contraction. Come, these two words come from … expand and contract.*	'expansion' ← 'expand'; 'contraction' ← 'contract'
	Long/short forms of a word	T1: *Laboratory is the long word for lab.*	'lab' vs. 'laboratory'
Different text types		T3: *Izzat says* 'I predict that the ball will gain heat and it will expand'. *Ok, then what did you write here for 'my explanation'? … What do I write here when I talked about prediction? … Ok so I actually want to know what do you think will happen?*	Prediction vs. explanation;
Question-answer types		T1: *I said* 'what happened to the temperature in liquid A'. *I didn't say how it feels like.*	What the water feels like vs. what happened to the temperature
Writing styles		T1: *This is a colloquial way of saying it. Let's frame it in the scientific language style.*	Scientific vs. colloquial

At the text level, differentiation occurred particularly with respect to its types and styles. Instances of texts belonging to three subcategories illustrate language demands that go beyond understanding the substantial content of science to include those pertaining to the pedagogical and assessment practices that are part and parcel of learning science through language within the classroom context. These practices include answering different types of school-based assessment questions, and constructing texts that served different purposes or with distinct writing styles.

The variety of differences between the contrasting pairs of linguistic items pointed to the possible ways that confusion could set in among the students. These confusions are likely to be more obscure compared to students' basic failures of knowing the label of an entity or the meaning of a linguistic item for several reasons. The discernment itself often demands a cross-contextual understanding that goes beyond the immediate context of language use to realise the existence of the other meanings and uses. First, differentiating between two meanings of a word would demand the recognition that the same word can have different meanings across contexts (everyday versus scientific). Second, confusion among terms can also arise because of their tendency to co-occur in the same sentence or text, which may give rise to the mistaken impression that they are synonymous with each other. Third, such difficulty can be further compounded by the tendency of defining terms in relation to each other (Halliday, 1993). Unless explicitly highlighted (foregrounded), the subtle differences between these terms may remain elusive to students who are new to the topic and to the English language.

Selecting appropriate language choices

While the **differentiating** process served to clarify possible items (forms, meanings or types) and to avoid confusion between linguistic items (words/phrases or texts), the process of **selecting** has the additional function of making explicit which linguistic item and meaning ought to be employed in preference over another item or meaning in a particular context. The functions of various categories are unique and supplemental; **labelling** focuses on the form, **explaining** focuses on the meaning, **differentiating** focuses on the form, meaning or type, while **selecting** focuses on the coordination of the form and meaning of a linguistic item within the context of its use. In explicating which word/phrase was preferred over another or rejected, the teachers were distinguishing between the forms of language and simultaneously highlighting which form was the acceptable or appropriate to represent a specific meaning (i.e. the form–meaning connection).

Selecting served as a process of delimiting, that is, setting the boundary within which a specific word/phrase can be used. The preference of one use over another could occur for four reasons as set out in Table 4 (Appendix D provides a more comprehensive listing).

The first two types of instances (scientific words, context-appropriate words) tended to occur when a new concept or term was being introduced, whereas the last two types (grammar, specificity of the words) tended to occur when the focus of the lessons was on application of the concepts while answering school-based science questions. In comparison to the **explaining** and **differentiating** processes, which foregrounded the

Table 4. Some instances found within the functional category of **selecting**.

Type	Illustrating transcript	Instance
Scientific words (instead of non-scientific words)	T1: *Did I take temperature readings or did I take heat readings?*	'temperature reading' (not 'heat reading')
Context-appropriate words (instead of context-inappropriate words)	T1: *Ok, this is a better word* [refers to the word 'inflated' on the board] *compared to the balloon* 'becoming bigger'. *Because the balloon actually didn't become bigger, … the balloon is filled up with something.*	Balloon 'inflated' (not 'becoming bigger')
Grammar: comparative and superlative adjectives, prepositions, word forms	T1: *Ok, because you are comparing 3 things, … you have to think of the superlative. Instead of slower, it must be?*	Superlative adjectives ('slowest' not 'slower')
Specificity of words (usually lack of)	T3: *Becomes … difference in size? It can be from big to small, small to big. Not specific enough.*	'water level in the glass tubing' (preferred over 'the water level')

interpretive process of understanding the language of science, the process of **selecting** as with the process of **labelling** foregrounded the representational demands of science, that is, the needs to use specific or precise semiotic resources for representing meanings that constitute the substantial content of science.

Constructing text

The **constructing** process involved addressing the language demands inherent in the generation of texts to represent the scientific meanings that have been made available during the lessons. This process demanded the explicit coordination of the form and meaning of the linguistic resources with a specific type of text (i.e. form–meaning–text connection). The texts being constructed ranged from simple fill in the blanks to different types of school-based science questions.

The **constructing** text process could be further decomposed into a number of subprocesses that served to scaffold the overall purpose of generating texts of different kinds (Table 5). These subprocesses revealed the nature of the language demands integral to the construction of textual products, a process that was particularly dominant in the second half of the instructional sequences. The instances included in Table 5 are not

Table 5. Subprocesses of **constructing** and their typical instances.

Type	Illustrating transcripts	Typical instances
Spelling	T3: *Please learn to spell it correctly. If you wrote it wrong, I want you to do corrections for that word.*	'Bunsen burner'; 'degree Celsius'; 'thermometer'
Using fill-in-the-blank as prompts	T2: *Now, what caused what I see happening? The heat caused the water to?*	'The heat cause the water to'
Using sentence starters	T1: *So we say inference:* 'this shows that' *right?*	'This shows that' [for inference]; 'This is due to' [for reason]
Using question prompts	T1: *Ok, the observation is B has the biggest volume, so what does it show?*	'What can we/you see? [for observation]; 'what can we infer/tell about … .?' [for inference]
Using logical connectives	T1: *When you are explaining the cause or the reason, you often use words like* 'because' *or* 'when'.	'because'; 'and'; 'therefore'; 'however'
Using key words/phrases	T1: *You must have this* 'gain heat, lose heat' *first, ok?*	'gain heat from'; 'lose heat to'
Using structural components	T1: *In most explanations, there's a cause and there's an effect. Ok, so let's look at this part here. We are saying here temperature increases. What are some possible causes of temperature increase?*	Explanation is constituted by observation, inference and reason or contained cause and effect
Bringing components together (synthesis)	T1: *Ok, we now have a format of presentation, starting with observation, inference and reason. So now, part 7 is when you combine all 3 sentences into 1 paragraph.*	Through the observation-inference-reason structure
Checking adequacy	T1: *So when you are writing your answer, when you are checking, you notice that if either the cause or the effect is missing, you know that something is not quite right. … Ok, so this would be an example of a complete answer, with the cause and the effect.*	Checking for missing components; checking for presence of key words/ phrases
Commenting on syntax (including tenses used)	T2: 'The water level has been higher.' *Grammar is not there.*	Inappropriate use of past perfect tense when making a prediction
Commenting on style/ convention	T1: *Factually you are not wrong. Ok, it's just like in composition, there is a beginning paragraph, there's a middle paragraph, and there's a conclusion*.	The need for structure as in English writings

exhaustive, but only representative of what the teachers attended to for this particular category.

A key subprocess invoked in the construction of texts was unpacking the components that constitute scientific explanations, such as for explaining the effects of heat or the choice of using a particular material in reducing heat loss. The three main components were observation, inference and reason, each of which was a type of text in its own right. This subprocess tended to occur alongside several subprocesses, which included eliciting these components through question prompts (e.g. 'What can I see?' for observation) and sentence starters (e.g. 'This is because' for reason). Having elicited these components, two other subprocesses involved synthesising the components together into a coherent explanation and checking the adequacy of the explanation. The structural components and the associated prompts provided the students with anchors for generating explanations and the basis for evaluating their adequacy.

Another subprocess common and pervasive across all the Grade 4 classes was the emphasis on specific key words/phrases that were associated with the various kinds of explanation. These key words/phrases provided the students with essential linguistic resources on which they could build the texts. Other peripheral subprocesses that were invoked in the text construction process include spelling, using fill-in-the-blank as prompts, the use of logical connectives as linkages and commenting on the syntax and styles of the texts. On some occasions, the specific purpose of the logical connectives in terms of the relationship connoted was explicated. The syntax of sentences was seldom a focus of the teachers and in fact sometimes identified by teachers as something that the students need not be overly concerned with unlike during language arts lessons.

Deconstructing text

Deconstructing, a reverse process of **constructing**, involved explicating the structural components and features of a pre-existing text. Unlike **constructing**, which has the purpose of generating texts, **deconstructing** served mainly the purpose of text analysis and genre recognition. Only two instances of **deconstructing** were identified: 1. Deconstructing definitions, and 2. Experimental reports (features/structure). In the case of definition, the teacher identified similar grammatical features among the different examples of definition, whereas with the experimental report instance, the teacher elicited the various components (such as the aims, materials and procedures) that constituted an experimental report. Highlighting the linguistic features and structures of a text type has the effect of relating the form, meaning and type of texts together. However, this process was relatively rare despite its importance in developing students' ability to interpret different types of text in textbooks and workbooks.

Pronouncing

Similar to language arts lessons, the teachers would occasionally (though infrequently) elicit from students the pronunciation of certain words that appeared in the written texts (T: 'How do you pronounce this word?'). Although the pronunciation was highlighted in the talk, likely for the benefit of the ELL students, it might not be the only focus of the teachers. The instances (e.g. 'observation', 'inference', 'reason') that were highlighted in the teachers' talk appeared more likely to be an attempt to stress their importance in the science terminology since many of the students were likely to have minimal difficulty with their pronunciation.

Summary

The first five functional categories (**labelling**, **explaining**, **differentiating**, **selecting** and **constructing**) were the most frequently documented and characterised by the diverse instances identified within each category. They could arguably be considered the major foci of these elementary school teachers in their attempts to foreground the language demands of science in this unit of study for these students, while the other two functional categories (**deconstructing** and **pronouncing**) appeared to be less important foregrounding foci. The ALDIS framework revealed the numerous ways in which the features, norms and conventions of scientific and English language inherent in the Grade 4 topic – Heat and Temperature – were brought to the students' attention and illustrated the complexity of the language demands that would otherwise be missed if only a conceptual lens had been employed to examine classroom talk. The ALDIS framework provides the general architecture that might be expanded or modified when considering teacher foregrounding in other science topics and grade levels. Two assertions about the language demands and disciplinary literacy learning associated with the classrooms flow from the results of this study.

Assertion 1: The language demands were extensive

The extensiveness of the language demands is evident in the multitudes of ways in which the form, meaning and type of words/phrases, sentences and texts were explicated. Some of these language demands coincide with the conceptual demands (such as the need to differentiate between 'heat' and 'temperature') identified in existing literature on students' conceptions. In fact, the first category of **labelling** can be said to overlap with the notion of concept formation, which involves associating a label with a central object, event or idea. Furthermore, the second and third categories (**explaining** and **differentiating**) overlap with concept attainment (knowing leading to deeper understanding), that is, establishing the critical, essential attributes of the concept and contrasting the set of examples with a set of non-examples to verify the nature of defining and distinguishing critical attributes of a concept. However, not all instances identified within these categories would be given much explicit attention in the traditional conceptual instruction approach since they are not strictly scientific concepts per se. Examples include the **labelling** and **explaining** of academic and everyday terms and **differentiating** between referents, synonyms or hyponyms. Learning about these semiotic resources, which span across everyday, academic and scientific language, provides the foundation upon which the scientific conceptual understanding can be developed concurrently by the students and levels the three-language problem across learners with different home languages and language proficiencies.

The findings thus demonstrated the concurrent and interdependent roles of learning of, about and through language within science classrooms. This study adds to our understanding of the demands that students encounter in learning about heat and temperature that would otherwise be missed without taking a sociosemiotic perspective.

Note that as these instances were only identified from talk that foregrounded the language demands, there could be other linguistic resources pertinent to the topic that were not captured by the ADLIS data selection and analysis framework. These could either be assumed by the teachers as readily understood by students or their meanings were explained implicitly. Nonetheless, given the teachers' attention to the instances identified, they appear to be fairly representative of the scope of language demands that the culturally and linguistically diverse Grade 4 students had to deal with for this topic. Extrapolated to other topics and school levels, the language demands can be expected to be even more substantial.

Assertion 2: Disciplinary literacy was built not only on basic and intermediate literacy but develops in parallel with them

The extensiveness of the language demands raises the question of whether the model of literacy development proposed by Shanahan and Shanahan (2008) is an adequate representation of the learning progression undertaken by these Grade-4 science students. Their model proposed that discipline-specific literacy (particularly, reading) is built on the foundation of both basic and intermediate literacy, and becomes progressively more prominent as students enter middle school and high school. However, the nature of the many instances identified in this study suggests that the kind of literacy that these students were expected to acquire was in fact proportionately more discipline-specific. It appears that the students were expected to concurrently acquire the disciplinary literacy of science alongside the literacy demands of everyday and academic English during the topic sequence. This occurred despite the fact these Singaporean students were only in their second year of formal science instruction. For example, most of the vocabularies that the students needed to acquire in the categories of **labelling**, **explaining** and **differentiating** were in fact discipline-specific terms that the students were more likely to have access to in classroom setting than in their daily life. Even the texts that the students were expected to construct and the various ways in which they were supported in constructing these texts could be considered science-specific. It may be more accurate to represent the literacy development of these students as Figure 2, which shows the co-development of discipline-specific and general academic literacy as students progress towards higher level of schooling and deeper consideration of specific science topics. These types of literacy build on and are strengthened by the other in a recursive loop that reinforces the learning of the subject matter and understanding of the scientific enterprise (Fang, 2012b). General academic and discipline-specific literacies thus play important roles in learning a subject matter at all learning stages, and provide support for Fang and Coatoam's (2013) claim that disciplinary literacy instruction can (and does in fact as shown in this study) begin at the upper elementary grade levels. The simultaneous development of the co-dependent, mutually reinforcing literacies in turn takes place within the context of the three tightly intertwined modes of learning emphasised in Halliday (1993)'s language-based theory of learning and represented as the outer circle in Figure 2. It is through the learning of, about and through language (general academic and disciplinary-specific) that equips students with progressively more advanced academic and scientific language and literacy skills that prepare them for future learning and identifies them as scientifically literate.

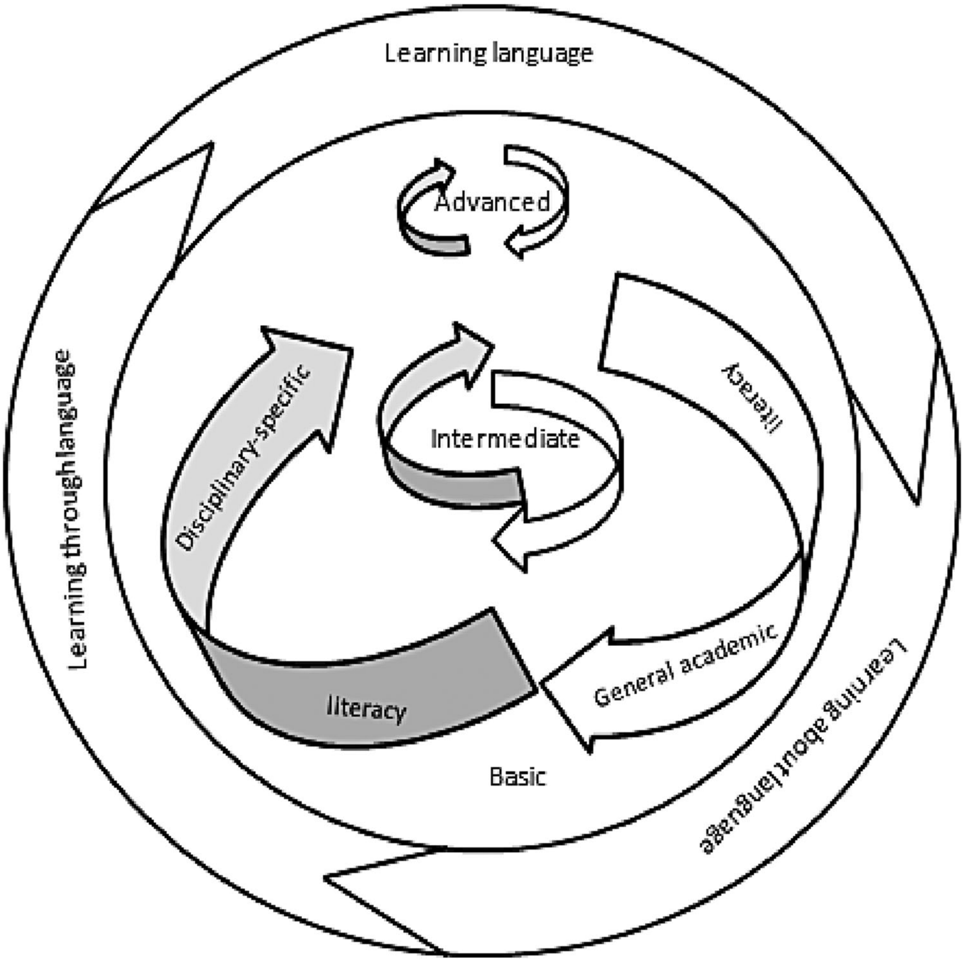

Figure 2. A revised representation of literacy progression combined with language-based theory of learning.

Limitations of study

This study is limited in at least two ways. First, the findings and the assertions may not apply to other science classrooms in which different instructional approaches were used to engage different grade level and less diverse students and to teach different science topics. Nonetheless, these findings and assertions provide preliminary insights about the demands of language and literacy learning in science and raise questions about the assumptions we might have about primary science that warrants further examination, in particular the extent and nature of the language demands that beginning science learners have to grapple with. Second, those categories that constitute the ALDIS framework may not be exhaustive since the framework is empirically derived from a single topic, four classes and three teachers. Other topics and science and engineering practices could have distinct language demands (visual representations, mathematical calculations, web-based resources, etc.) and more categories could be identified from other lessons (representing, arguing, processing data, etc.). Likewise, different instructional approaches might additionally change the proportions of instances distributed across categories and sequential occurrence of specific functional categories. Nonetheless, the existing categories, especially the first five that were found applicable to all four classes, are most probably applicable to other lessons and grade levels.

Methodological implications

The resulting ALDIS framework provides a useful analytical scheme for understanding the extent to and ways in which students are supported in their language development within the context of authentic diverse classrooms. The flexible architecture allows for comparing and expanding how language support and development vary across different topics, disciplines, pedagogical approaches and classrooms and their possible impacts on both students' conceptual understanding and disciplinary literacy. Its application can also identify gaps in an instructional sequence when comparison is made with the expected curriculum or with the findings from other classrooms. The focus in this small-scale topic-specific study is on drawing together the findings from across classrooms; therefore, differences among them are outside the scope of this study. Future larger-scale research that identifies these differences may provide additional insights about the possible instructional enhancements that could have been made in the individual classes. It is important to note, however, that not all differences necessarily indicate deficiencies on the teachers' part since they would have to consider the specific needs of their students with varying knowledge base, experiences, English proficiencies and linguistic abilities. More important than the differences across classrooms are perhaps the inconsistencies that may exist within a classroom. For example, it is possible that a teacher may define one term as equivalent to another and yet explicitly reject the use of one of them without justification, resulting in possible confusion among students. In such cases, identifying such inconsistencies in spoken discourse can help to raise awareness of tensions in classroom talk that might impede students' understandings.

Applying the ALDIS framework to more topics, grade levels and disciplines can allow the tracking of language demands across the developmental progression of students in the learning of science and other subjects. Such a study would mirror that of Christie and Derewianka (2008) in which they examined K-12 students' writings and traced their science writing capacity across stages ranging from early childhood to late adolescence. This may provide a trajectory of the language development specific to science that goes beyond those found for writing. The insights gained can help inform curriculum design particularly on what aspects of the language and literacy skills need to be focused on at different grade levels and topics so that students are equipped with the semiotic tools needed. The ALDIS framework applied to lessons on other subject matters can be a way to identify discipline-specific language demands that are empirically grounded in education settings and compared to those identified from discipline experts (Shanahan, Shanahan, & Misischia, 2011).

Pedagogical implications

The topic-specific language demands identified in this study can inform classroom teaching by alerting teachers to aspects of language that may need explicit attention and raising their sensitivity to their students' potential misrepresentations. The ALDIS framework itself can also be employed as a lesson-planning tool for generating relevant English and scientific language objectives and determining their relative placement within a common core curriculum, lesson or unit of needed foregrounding.

One question that might be raised of the findings are the possible reasons for the teachers' emphasis on the language demands in contrast to other contexts where teachers tend not to emphasise language demands. One possible reason relates to the elementary school context, where generalist teachers who are often required to teach multiple subjects could be better placed to recognise the intertwined nature of both language (academic and disciplinary) and content development in their students. Examination-oriented instruction, commonly found in Singapore, could be another reason contributing to the strong emphasis on language and literacy instruction in the classes (Seah, 2016a). With assessment primarily in the written mode, the teachers recognised that written literacy is an important co-requisite aspect of academic performance. Nonetheless, the extent to which the teachers attended to the learning of language raises questions about the effectiveness of the instructional approach, as an overriding concern on language may come with the risk of fostering rote learning over conceptual understanding (Brookes & Etkina, 2015). As it is outside the scope of this study to evaluate the impacts of the teachers' talk, it remains an open question as to how effective the teachers' talk (as a whole) is in promoting students' conceptual understanding and precise use of scientific language simultaneously. The level of precision of language that would be reasonable for primary science education would also have implications on the scope and sequence of curriculum, learning progression and expectations of assessment standards. Future studies could explore how teachers' talk about the language demands relates to the students' engagement of science, sense-making and reasoning and students' language development. Such studies are likely to provide a more robust professional developmental framework for disciplinary literacy teaching. This study raises more questions than it set out to study, highlighting once again the potentialities and the needs for more research in the area of disciplinary literacy (Moje, 2007).

Acknowledgements

The author is grateful to the teachers and students who participated in this study and would also like to acknowledge the contribution of Ms Teresa Ong and Ms Gracelyn Tan Yen Leng for their help with the analysis.

Disclosure statement

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the position, policy or endorsement of the funding agency.

Funding

This work was supported by the National Institute of Education (Singapore) [grant OER 65/12 SLH].

References

Braden, S., Wassell, B. A., Scantlebury, K., & Grover, A. (2016). Supporting language learners in science classrooms: Insights for middle-school English language learner students. *Language and Education*, *30*(5), 438–458.

Brookes, D. T., & Etkina, E. (2015). The importance of language in students' reasoning about heat in thermodynamic processes. *International Journal of Science Education*. doi:10.1080/09500693.2015.1025246

Buxton, C. A., & Lee, O. (2014). English learners in science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 204–222). New York, NY: Routledge.

Carlsen, W. S. (2007). Language and science learning. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 57–74). Mahwah, NJ: Lawrence Erlbaum Associates.

Christie, F. (2005). Speech and writing (chapter 4). In F. Christie (Ed.), *Language education in the primary years* (pp. 48–63). Sydney: University of New South Wales Press.

Christie, F., & Derewianka, B. (2008). *School discourse: Learning to write across the years of schooling*. London: Continuum.

Department of Statistics. (2011). *Census of population 2010 statistical release 1: Demographic characteristics, education, language and religion*. Retrieved from http://www.singstat.gov.sg/publications/publications-and-papers/cop2010/census10_stat_release1

Fang, Z. H. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335–347.

Fang, Z. H. (2012a). Approaches to developing content area literacies: A synthesis and a critique. *Journal of Adolescent & Adult Literacy*, *56*(2), 103–108.

Fang, Z. H. (2012b). Language correlates of disciplinary literacy. *Topics in Language Disorders*, *32*(1), 19–34. doi:10.1097/TLD.0b013e31824501de

Fang, Z. H., & Coatoam, S. (2013). Disciplinary literacy: What you want to know about it. *Journal of Adolescent & Adult Literacy*, *56*(8), 627–632.

Frändberg, B., Lincoln, P., & Wallin, A. (2013). Linguistic resources used in Grade 8 students' submicro level explanations – science items from TIMSS 2007. *Research in Science Education*, *43*(6), 2387–2406. doi:10.1007/s11165-013-9363-0

Gee, J. P. (2004). Language in the science classroom: Academic social languages as the heart of school-based literacy. In W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 13–32). Newark, DE: International Reading Association; NSTA Press.

Glaser, B. G. (1992). *Basics of grounded theory analysis: Emergence vs forcing*. Mill Valley, CA: Sociology Press.

Gonzalez-Howard, M., & McNeill, K. L. (2016). Learning in a community of practice: Factors impacting English-learning students' engagement in scientific argumentation. *Journal of Research in Science Teaching*, *53*(4), 527–553.

Greeno, J. G., & Collins, A. (2008). Commentary on the final report of the National Mathematics Advisory Panel. *Educational Researcher*, *37*(9), 618–623. doi:10.3102/0013189X08327997

Grimshaw, A. D. (2003). Genres, registers, and contexts of discourse. In A. C. Graesser, M. A. Gernsbaher, & S. R. Goldman (Eds.), *Handbook of discourse processes* (pp. 25–82). Mahwah, NJ: Lawrence Erlbaum Associates.

Halliday, M. A. K. (1993). Towards a language-based theory of learning. *Linguistics and Education*, *5*, 93–116.

Halliday, M. A. K. (2004). *The language of science*. In Jonathan J. Webster (Ed.). New York, NY: Continuum.

Kelly, G. J. (2007). Discourse in science classrooms. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 443–469). Mahwah, NJ: Lawrence Erlbaum Associates.

Kelly, G. J. (2014). Discourse practices in science teaching and learning. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 321–336). New York, NY: Routledge.

Lee, O., & Luykx, A. (2007). Science education and student diversity: Race/ethnicity, language, culture and socioeconomic status. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 171–197). New York, NY: Routledge.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Pub. Corp.

Ministry of Education. (2007). *Science syllabus primary 2008*. Singapore: Ministry of Education.

Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education*, *31*, 1–44.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead: Open University Press.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240.

Schleppegrell, M. J. (2004). *The language of schooling: A functional linguistics perspective*. Mahwah, NJ: Lawrence Erlbaum.

Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Conceptual knowledge in talk and text: What does it take to understand a science question? *Instructional Science*, *29*, 213–236.

Seah, L. H. (2016a). Elementary teachers' perception of language issues in science classrooms. *International Journal of Science and Mathematics Education*, *14*(6), 1059–1078.

Seah, L. H. (2016b). Understanding the conceptual and language challenges encountered by grade 4 students when writing scientific explanations. *Research in Science Education*, *46*(3), 413–437.

Seah, L. H., Clarke, D. J., & Hart, C. (2014). Understanding the language demands on science students from an integrated science and language perspective. *International Journal of Science Education*, *36*(6), 952–973.

Shanahan, C., Shanahan, T., & Misischia, C. (2011). Analysis of expert readers in three disciplines: History, mathematics, and chemistry. *Journal of Literacy Research December*, *43*(4), 393–429.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review*, *78*(1), 40–59.

Shananhan, M.-C. (2012). Reading for evidence through hybrid adapted primary literature. In S. P. Norris (Ed.), *Reading for evidence and interpreting visualizations in mathematics and science education* (pp. 41–63). Rotterdam: Sense Publishers.

Tippett, C. D. (2011). *Exploring middle school students' representational competence in science: Development and verification of a framework for learning with visual representations* (Unpublished PhD thesis). University of Victoria, Victoria, British Columbia, Canada.

Unsworth, L. (2001). Evaluating the language of different types of explanations in junior high school science texts. *International Journal of Science Education*, *23*(6), 585–609.

Vygotsky, L. S. (1986). *Thought and language*. Cambridge, MA: The MIT Press.

Walsh, S. (2006). *Investigating classroom discourse*. Oxon: Routledge.

Wellington, J. J., & Osborne, J. (2001). *Language and literacy in science education*. Philadelphia, PA: Open University.

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research*, *72*(2), 131–175.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy — empowering research and informing instruction. *International Journal of Science Education*, *28*(2), 291–314.

Yore, L. D. (2012). Science literacy for all: More than a slogan, logo, or rally flag! In K. C. D. Tan & M. Kim (Eds.), *Issues and challenges in science education research: Moving forward* (pp. 5–23). Dordrecht: Springer.