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Understanding Middle School Students' Difficulties in Explaining Density Differences from a Language Perspective

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This study examines how a class of Grade 7 students employed linguistic resources to explain density differences. Drawing from the same data-set as a previous study by, we take a language perspective to investigate the challenges students face in learning the concept of density. Our study thus complements previous research on learning about density which has mostly focussed on the conceptual challenges. The data consist of transcripts of lessons on density and students' written assignments. Using selected analytical categories from the Systemic Functional Linguistics framework, we first examined students' use of linguistic resources in their written reports of a practical activity. We then compared the language employed by the students with the instructional language, identifying possible links. Our analysis identified specific aspects of language that the students need to appropriate in order to express an understanding of density that aligns with a scientific perspective. The findings from this study illuminate ways by which teachers could assist students in overcoming the linguistic challenges in explaining density differences, which complement those made by existing studies that focus on conceptual challenges.

Keywords: *Students' writings; Instructional language; Lexicogrammatical resources; Systemic Functional Linguistics; Density*

Introduction

The development of students' understanding of density has been extensively investigated. However, most existing studies have sought to understand the conceptual

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challenges that students encounter from either an alternative conceptions approach or a proportional reasoning perspective (e.g. Hewson, 1986; Smith, Maclin, Grosslight, & Davis, 1997). As pointed out by Xu and Clarke (2012), few studies have examined the consequences which classroom interactions might have for students' evolving understanding of the concept of density. Using the theory of distributed cognition as a theoretical and analytical lens, Xu and Clarke (2012) illustrated how ambiguities inherent in specific classroom interactions contributed to student's learning difficulties. The present study attempts to build on what they have uncovered.

Using an integrated socioconstructivist and sociosemiotic framework, we analyse the same data-set with a lexicogrammatical (LG) lens. This reveals other aspects of the classroom interactions that might have compounded the challenges for the students in these lessons and suggests strategies that may improve classroom instruction. We favour the use of the term *LG resources* (over *linguistic resources*) as it makes explicit our focus on both the lexical items (i.e. technical and non-technical vocabulary) as well as the grammatical resources (e.g. pronouns, conjunctions, prepositions) employed in the language.

To date, there has been little research on how the LG resources used in the classroom might shape students developing understanding of specific science concepts, including density. This is despite the wide call for emphasis on language in learning the content knowledge of science (Halliday & Martin, 1993; Lemke, 1990; Mortimer & Scott, 2003; Norris & Phillips, 2003; Wellington & Osborne, 2001). In previous studies (Seah, Clarke, & Hart, 2011; Seah, Clarke, & Hart, 2013), we productively utilised this analytical approach to identify the language-related challenges students encountered when explaining the phenomenon of 'expansion'. Similarly, this study expands our understanding of the language-related challenges students may encounter that are specific to particular science topics, in this case density.

Viewing Students Learning about Density within a Conceptual Framework

It is well known that density is a concept that causes students significant difficulties (e.g. Dawson, 1981; Hewson, 1986; Hewson & Hewson, 1983; Smith, Carey, & Wiser, 1985; Smith et al., 1997). Density is commonly defined in middle school science either as a ratio of mass to volume or as mass per unit volume (Smith et al., 1997, p. 319). Previous research has identified inherent features of this concept that contribute to the learning demand:

- Density involves 'a complex proportional relationship' (Hewson, 1986, p. 167) and simultaneously changing variables (Smith et al., 1997).
- Density can only be perceived through calculation rather than with direct senses (Smith et al., 1997).

As with many other scientific concepts, students may also have alternative conceptions that interfere with their understanding of the concept of density. An early precursor to the concept of density may be described by the phrase 'heavy for size' (Smith et al., 1985, p. 178). Before this develops, young children tend to separate the two concepts of weight and size. The notion of 'heavy for size' tends to conflate the two concepts of weight and density, and constitutes the general notion of heaviness (Hewson & Hewson, 1983). Hewson (1986) found that some students interpreted density at the submicro level in terms of the packing of particles, effectively equating density to the notion of 'denseness' with the latter referring to the quantity of entities in a certain volume. Such a submicro representation may be incomplete as it also depends on students' conceptions of mass and volume in terms of the arrangement, the concentration and the mass of the particles. Other studies indicated that students' alternative conceptions of volume (Dawson, 1981), weight[1] and matter (Smith et al., 1997) also played a role in constraining their understanding of density.

However, Kloos, Fisher, and Van Orden (2010) challenged the extent to which students' prior conceptions constrained their understanding of density. Through a series of experiments they demonstrated that task constraints could in fact play a greater role in influencing students' performances in density task compared to their prior conceptions. Their findings mirrored an earlier study by Fassoulopoulos, Kariotoglou, and Koumaras (2003) who found that when children between the ages 12–15 years old were asked to perform tasks involving intensive qualities, specifically density and pressure, 'a significant percentage of the pupils provide inconsistent answers, that is, they change their reasoning across tasks and use alternatives to scientific reasoning, influenced by phenomenological features of the tasks' (p. 71).

The research discussed above has focused on the conceptual challenges of learning density either from an alternative conceptions or a proportional reasoning perspective. Suggestions for pedagogical interventions consequently have focused on addressing students' alternative conceptions and reasoning abilities (e.g. Hewson & Hewson, 1983; Smith et al., 1997). Thus far, the role played by classroom interactions in students' learning of the density concept has been neglected (Xu & Clarke, 2012). In their study, Xu and Clarke (2012) attempted to address this gap by adopting the theory of distributed cognition to show how ambiguities inherent in the whole-class discussion contributed to student difficulties with the concept of density. They attributed the ambiguities mainly to 'the limited connection between the macroscopic and microscopic views of density' (p. 788), which in turn could be attributed to the lack of differentiation between the density of a substance from that of an object. In response to their findings, their pedagogical recommendation emphasises the need for a conceptual framework that provides a coherent notion of substance that would allow bridging the two views of density, such as that found in Johnson and Papageorgiou (2010). Their analysis thus highlighted aspects of classroom interactions that could interfere with the development of a conceptual understanding of density.

An LG Approach to Understanding Students' Challenges in Learning about Density

In this study, we adopt a theoretical synthesis of the socioconstructivist and the sociosemiotic perspectives (see Figure 1) as our basis for considering the learning demands of the topic of density from a language perspective.

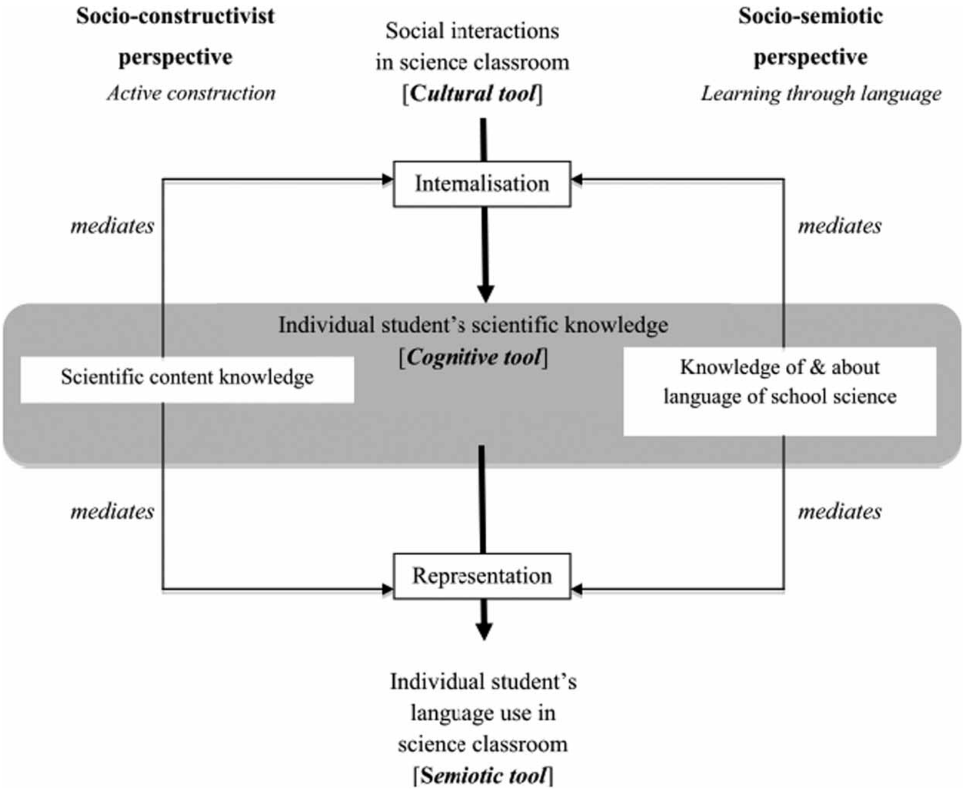


Figure 1. A theoretical synthesis of socioconstructivist and sociosemiotic perspectives (Seah et al., 2011)

This integrated framework was first adopted in our previous study examining students' use of LG resources related to 'expansion' (Seah et al., 2011). The socioconstructivist view we have employed has its theoretical underpinning in Vygotsky's (1978) general genetic law of cultural development, which emphasises the role of language as providing the cultural and cognitive tools for the construction of scientific knowledge. Studies of classroom interactions, including that of Xu and Clarke (2012), have mostly paid attention to this role of language as cultural and cognitive tool. However, language also serves as a semiotic tool, essential for both the construction and representation of knowledge. Halliday (1993) asserted that 'language is the essential condition of knowing, the process by which experience *becomes* knowledge' (original emphasis, p. 94). The process of transforming experience into meaning, producing knowledge which he termed 'understanding' (Halliday, 2004, p. 119), is realised through the lexicogrammar. The latter comprises syntax, morphology and vocabulary: it realises the creation of a semiotic universe that runs parallel to the physical one. He pointed out that the phenomena of the world can be perceived in infinite ways: it is grammar that determines our perception of the world by imposing categories and relationships on it. A threefold perspective of learning was proposed by Halliday

(1993, p. 113): 'learning of language, learning through language and learning about language'. This triptych captures both what a student goes through in a language as well as the language demands placed on her in a science classroom. Concurrently as she is learning science through language, she is learning the language of and about school science, though often at an unconscious level.

From the socioconstructivist perspective, learning science is an active process that depends on the active construction of meaning by the learner (Leont'ev & Wertsch, 1981). A learner's preexisting knowledge plays a critical role in this process (Pines & West, 1986). Such preexisting knowledge from the sociosemiotic perspective includes not only content knowledge but also knowledge of and about the language of school science. The distinctive but intertwined processes of learning of, through and about the language of school science could explain why students' difficulties with the use of language in science can be of several kinds. In some cases, students may not have the necessary knowledge of and about the language of science to interpret the social interactions taking place during instruction in the way expected. This in turn could lead to misconceptions and misapplication of scientific knowledge. The second type of cases involves the difficulty of representing their scientific understandings with the language of science. Within science classrooms, multimodal representations (e.g., gestures, diagrams, physical artefacts, demonstrations) are often available for sense-making but students are expected to represent their understanding in mainly linguistic form. Consequently, even if they may have little difficulty understanding science concepts (as evident from other semiotic tools such as drawing), they may be less competent with expressing their understanding in written form. Schleppegrell (2004) highlighted the difficulty in moving 'from the specific retelling of an experience to the general description of a scientific process' (p. 117) without an adequate repertoire of linguistic tools. In the above cases, the language used in the instruction is presumed to be unproblematic, which is not necessarily the case, as shown by other studies (such as Thörne & Gericke, 2014) . This constitutes a third possible kind of difficulties students could encounter with the language of science. In this study, we have chosen to foreground the second kind of difficulties given that it is often the neglected aspect of both instruction and research given the paramount concern on conceptual understanding/misconception in science learning.

Our analysis draws upon other work on the language demands of science learning (such as, Fang, 2006; Halliday & Martin, 1993; Schleppegrell, 2004; Veel, 1997). Underpinning this body of work is the Systemic Functional Linguistics (SFL) framework which attempts to link the use of LG resources to the meanings realised and to the social and cultural contexts in which the language is employed (Halliday, 1994). According to this functional–semantic view of language, every single clause realises three concurrent meanings: experiential (as a representation), textual (as a message) and interpersonal (as an exchange). In this study, our focus is on the experiential meaning of clauses, which is about how learners employ language to represent 'what goes on around them and inside them' (Halliday, 1994, p. 106).

To analyse the experiential meaning of a clause, the following linguistic classes were used:

- *Process*: It is typically expressed by a verb or a verbal group, and is associated with a small set of *Participants* such as *Medium*, *Agent* and *Range*.
- *Medium*: It is typically expressed by a noun or a nominal group and is the indispensable *Participant* without which the *Process* would not 'exist'; both the *Process* and the *Medium* constitute the core of the clause, which is the unit of the LG analysis.
- Agent: It is also typically expressed by a noun or a nominal group and is 'the entity that does or acts; the cause or instigator of a process' (Lemke, 1990, p. 222).
- *Range*: It can be expressed by a noun or an adverb and refers to 'the limits, extent, or nature of what the process does' (Lemke, 1990, p. 222).
- *Circumstance*: It is prepositional phrase, adverbial group or nominal group that expresses the circumstances (e.g. of reason, of condition, of location, of means, etc.) associated with the *Process* or the *Participants*.

An example of the various linguistic classes that can be found in a clause is shown in Table 1. The linguistic classes adopted in this study were taken from the ergative model which takes the *Medium* (the indispensable *Participant*) and the *Process* as the core of the clause. The *Medium* and the *Process* are in turn elaborated upon by *Circumstances and* other types of *Participants*, such as *Agent* and *Range*. A more detailed description of the ergative model which utilises these linguistic classes can be found in Halliday (1994). SFL thus provides tools for understanding how language functions as a system for making meanings, enabling the role played by language to be foregrounded.

Until recently, research utilising SFL in the context of science education has been dominated by literacy researchers who have tended to examine language features that are applicable to science learning in general (e.g. Christie & Derewianka, 2008; Fang, 2005; Halliday & Martin, 1993; Schleppegrell, 2004). This has not only led to an understanding of the language demands of learning science but also provided insights into how science instruction can be improved to tackle these demands. However, the recommendations offered seldom relate to specific topics. The use of SFL is now gaining currency among science education researchers such as Frändberg, Lincoln, and Wallin (2013) and Thörne and Gericke (2014), and this has given a rise to a greater focus on the specific literacy knowledge involved in representing scientific meanings related to particular topics (e.g. changes in matter with reference to particles, proteins). SFL has also been incorporated into analyses that go beyond verbal language in studies of multimodal representations in specific topics (e.g. Jaipal, 2010; Márquez, Izquierdo, & Espinet, 2006). However, in the case of the present study, multimodal representations were examined only to assist our interpretations of the language data.

Table 1. LG analysis of the experiential meaning of a clause

The marble	is	more dense	because of the materials in it
Medium	*Process*	*Range*	*Circumstance of Reason*

Data

The Research Setting

The participants in our study were a class of Grade 7 students in a secondary co-educational state school located in outer suburban Melbourne and their experienced science teacher, Mr Gardiner. There were altogether 27 students (10 girls and 17 boys) from diverse ethnic backgrounds. We focus here on the second lesson of a sequence of nine lessons on the topic ‘States of Matter’. The study took place early in the school year as students were beginning their secondary education. They came from several different primary schools, so some might have received little prior science instruction while others might have had more extensive science experiences.

During this lesson, Mr Gardiner introduced a definition of density and demonstrated the difference in density of two metal blocks (aluminium and lead) of equal volume. The students, working in pairs, then proceeded to a practical activity which required them to measure the mass and the volume of a piece of wax candle and a small glass marble. They measured the masses using an electronic balance, and determined the volumes through displacement of water using a measuring cylinder. They were supposed to then calculate the densities of the two objects with the given formula density = mass/volume. Though groups of students were seen discussing their results, students completed their practical reports individually and submitted them in the subsequent lesson. Prior to this lesson, the students learnt about the definition of matter, states of matter in the form of solid, liquid and gas and their distinguishing properties as part of the topic.

The ‘Causal Connections in Science Classrooms’ Study

The data for this study were generated as part of a larger project entitled ‘Causal Connections in Science Classrooms’, which had the explicit intention of looking at the same data-set with different theoretical lenses. The study by Xu and Clarke (2012) used distributed cognition as theoretical lens. Theirs was a deductive approach to the data: they first analysed the classroom interactions subsequently relating them to the difficulties students faced when learning about density. Drawing on the same data-set, but taking the synthesised social-constructivist and social-semiotic framework described above, our study took an inductive approach. We accomplished this by first examining what the students wrote following the practical activity and subsequently compared the students’ writings with the instructional language. In this study, the ‘instructional language’ refers to the language employed by both the teacher and students during whole-class discussion.

Within the context of the larger project, a team of researchers were involved in the data collection, and a variety of data generation techniques were used. The data included:

- video-recording of the lessons involving a total of four cameras (a teacher camera, a whole-class camera and two focus student group cameras)
- video-stimulated reconstructive individual interviews of one teacher and two focus students after each lesson
- collection of classroom artefacts such as teaching materials and students' written assignments

Of the data generated, those most relevant to this study were the students' written assignments and the lesson transcripts. The interview data, on the other hand, served as supplementary data that deepened our understanding of the context and, where applicable, allowed us to triangulate the meanings we ascribed to the students' writings.

Our study focused on how students constructed written explanations for the density difference between two objects. The analytical categories of the SFL framework allowed us to identify how LG resources functioned in the student's writings, and to differentiate subtle differences between the meanings students realised. We sought to understand how the language employed during whole-class instruction might have shaped the way students explained density differences. Our analysis was guided by the following research questions:

(1) When explaining density differences, what are the similarities and differences in the use of LG resources among students' writings?
(2) What are the similarities and differences in the use of LG resources between the students' writings and the instructional language?

Students' Writings

As stated earlier, the students' written assignments refer to their reports on the practical activity. In all, 23 students' practical reports were analysed (practical reports from 4 students were not available). Each practical report contained a table of results in which values of the mass, volume and density of the candle and the marble were recorded. Mr Gardiner explicitly requested that the written report consist of three main sections: 'Discussion', 'Evaluation' and 'Conclusion'; and all but two of the practical reports followed this instruction. Of the 23 practical reports available, 18 included an explanation for the difference in the densities obtained for the marble and the candle under the discussion and/or conclusion sections. These explanations are the focus of our analysis.

In their explanations, the students invoked a variety of reasons for the density difference and some students drew diagrams that we could compare with their written explanations. Unlike the teacher's demonstration, where the metal blocks being compared had equal volume, the students had to apply the language appropriated from the instructional language to account for the differences in density between two objects of different volume.

Instructional Language

During the lesson, two episodes of whole-class discussion occurred that made use of LG resources which students could have appropriated when writing their explanations for the different densities they measured.

The first episode took place early in the lesson and attempted to elicit the meanings students had for the word 'density'. During the discussion, Mr Gardiner was handing out sheets with the instructions for the practical activity.

T:	Now, yesterday, remember I write on the board about properties? Yeah? And I yeah I talked about shape and volume. Well, there's another thing that I can use to possibly talk about solids, liquids and gases. And that is the word density. Hands up if you think (of another word) the word, density, means. Gloria.
Gloria:	Something that is soft but it still has um like (…)(hard)(…)
T:	Something that is soft and hard. Yep, ok. Any other ideas? Cliff.
Cliff:	*How compact the atoms are*
T:	*How packed the atoms are or in fact particles*. Yep. That's a very good answer. [Teacher made sure some students had the practical worksheet]
T:	Right. Any other answers? For what is a—what is density? [Teacher confirmed with a student that he had a copy of the worksheet.]
T:	Any other takers? … Alright. If you look at the sheet here about density, … I want you to go to Point … six please. Do I have enough sheets? Ergh I should have more somewhere. Alright. I want you to go to Point six in the method. And it says 'Calculate the density.'
S:	Of each (object)
T:	Of each object. What's that formula say?
Gloria:	*Mass of object divided by volume of object*
T:	Ok. *The mass of it divided by the volume*. [Teacher showed students two metal blocks and confirmed with the students both metal blocks were of the same size and shape.]
T:	Now let's talk about density. Density you would, what did you say density was, Cliff?
Cliff:	*How compact at the atoms are (or particles)*
T:	*//How compact the atoms or particles are*

Two definitions of density were consequently established in this episode: Cliff's definition of density in term of the packing of particles; and the formula for density —that is, mass of the object divided by its volume. Cliff's definition in terms of particles could have been cued by the teacher's reference to particles in the previous lesson. In that lesson, Mr Gardiner had defined matter 'as a single particle or group of particles in some form of arrangement'. However, he did not elaborate further on the particle model of matter since he intended that this would be introduced later in the sequence of lessons. Cliff's definition suggests that he was likely to have some prior knowledge about the particle model of matter, but it is unlikely that all the students in the class shared his understanding.

The second episode of relevance occurred immediately after the first. Mr Gardiner began by asking students for their thoughts on the difference in density between an aluminium block and a lead block. During the discussion, the observation that these blocks were of identical shape and volume was first established.

T:	Alright. Well, which of these two, lead and aluminium, is going to be denser //and why? Cliff.
Kim:	Lead
S:	Lead
Cliff:	Lead
T:	And why did you say lead?
Cliff:	*Because because it's heavy and so (must have) more particles in it.*
T:	It's heavy because it got more particles. Ok. Fair enough. But yet these are the same volume, don't there?
Cliff:	(Yep)
T:	So in the formula, which says 'Mass divided by volume' you said that *lead is denser because it has?*
Kim:	*More mass*
Cliff:	*More particles contained in it*
T:	So if I put this on the—if I put these two blocks on the scale, what's going what's the lead going to … suggest compared to the aluminium?
Cliff:	*It'll be heavier.*
T:	Ok. Well, let's see. I've got the scale here from yesterday. Switch it on. … Well, let just crank it up. *So these these have the same volume.* So this lead weighs a hundred and seventy-eight grams. What do you think this going to weigh? [held up the aluminium block]
Kim:	Fifty something
Angie:	Ten
T:	Fifty something? Good guess. Forty-four grams. *So even though they have the same … volume, there is a hundred and forty gram difference.* So what Cliff said is true. *This lead even though it's the same volume must have particles that are packed more tightly.* I'm going to discuss more about particles and how well they packed when I talk about arrangement when I look at the particle theory. It's important (that) you know what in terms of ah density what it means. So *density is how much mass per volume.*

In this episode, Mr Gardiner emphasised that 'even though they have the same volume', the lead block was heavier and 'must have particles that are packed more tightly'. This explained the higher density. However, the fact that volume is also a variable in determining an object's density was mentioned in passing, but without the implications being considered. This was important because the objects whose densities the students were required to determine differed in volume as well as mass.

The reasoning in terms of particles in this episode appears to be incomplete, since the mass of individual particles plays as much a role in determining the density of a substance as the closeness of their packing. However, as Mr Gardiner explained in the post-lesson interview, his original intention was to rely on the definition of density as mass/volume; he had not intended to invoke a particle model to account for density differences. Significantly it was again Cliff who introduced particles into the discussion. In fact, the particle model of matter was only formally introduced to the students much later in the lesson sequence (in Lesson 5).

These two episodes cover the instructional language related to density that the students encountered prior to conducting the experiment to measure the densities of the candle and the marble. We have deliberately confined the scope of the instructional language to those discussions about density that occurred *before* the students commenced the writing of their practical reports. The purpose is to optimise the search for any differences in the use of LG resources between the students' writings and the instructional language.

Analysis

We addressed our first two research questions, using comparison and contrast as our main analytical techniques (Lemke, 1998). This first involved a content analysis of the students' explanations for the density differences between the candle and the marble. For this we used low-inference coding categories (Eisenhart, 2006) that led us to classify the explanations according to whether the difference in density was explained in macroscopic and/or submicroscopic terms. The macro and submicro references found within individual students' explanations provided a useful organising framework for the subsequent analysis. We then used the five categories from the ergative model of SFL (i.e., *Process, Medium, Range, Agent* and *Circumstance*) to classify the LG resources the students used in their writings. Although LG analysis proceeded clause by clause, the classification was based on the meaning of each clause as derived from the context in which the LG resources were employed (i.e. the entire practical report). Table 2 illustrates how three examples of clauses found in students' explanations were analysed. The LG analysis revealed subtle differences in the use of LG resources among the students' explanations which facilitated a second phase of content analysis. This phase of content analysis sought to determine the diversity of meanings within the macro and the submicro references. Finally we sought to identify similarities and differences in terms of the use of LG resources between the students' writings and the instructional language. The instructional language was not subjected to separate LG and content analyses as the use of the related LG resources in it was relatively consistent, unlike those among the students' writings. In any case, the way in which these LG resources were employed in the instructional language would essentially be revealed in the comparison between the students' writings and the instructional language.

Whenever additional data were available (e.g. video data, transcripts of classroom talk and interviews; other student artefacts), these were used to check the interpretations we were making. In some cases students had drawn diagrams in their practical

Table 2. Analysis of clauses that explain the difference in density between the marble and the candle

Example of student's explanation	Content analysis	LG analysis (of LG resources that explain the difference in density)
'The size of an object doesn't matter'	Macro reference	*Medium*: 'size of an object'
'It has less volume'	Macro reference	*Range*: 'less volume'
'The particles are closer together'	Submicro reference	*Range*: 'closer together'

reports and these were used to interrogate the corresponding verbal explanation. Our interpretations of the data were reviewed by fellow researchers who analysed the same data-set. Feedback collected during conference presentations of the study also fed into the final analysis. With these strategies, we sought to achieve consistency and validity in our interpretation of the data.

Findings

The findings from our analysis are presented according to the research questions, and in the same order, as set out earlier.

Similarities and Differences among Students' Explanations

Types of explanations. Through content analysis, two types of explanations were found among the students' explanations:

(1) Macro references: explained the difference in density in terms of the empirical properties of macroscopic entities (i.e. a macro-level representation).
(2) Submicro references: explained the difference in density in terms of the particle model of matter (i.e. a submicro-level representation).

Diversity of LG resources. LG resources found in the macro references were analysed separately from those found in the submicro references in our next phase of the LG analysis. Students' difficulties with distinguishing and connecting between the macroscopic and submicroscopic views of physical phenomena are well-established (Gilbert & Treagust, 2009). Not only do the two types of explanations necessitate the use of different LG resources, analysing them separately could also reveal students' difficulties related to the distinctions between the two views.

Macro references. The students employed a variety of LG resources to explain the difference in density between the marble and the candle at a macro-level (see Table 3). These LG resources can be broadly clustered into those that are related to:

(1) mass;
(2) volume or
(3) material (or characteristics)

Table 3 shows that LG resources related to mass, volume and material have been employed as *Ranges* in the students' macro references. Each *Range* often served as a standalone reason for the difference in density. This indicates that the difference in density had been accounted for mainly with reference to a single variable (e.g. 'the marble had a bigger mass'; or 'it has less volume'). Exceptions are when the explanations were accompanied by the *Circumstances of Condition*, such as 'if they were

Table 3. Diversity of LG resources employed in the macro references

Related to	Linguistic class	#Instances
Mass	*Range*	'heavier'; 'a bigger mass'; 'more mass'
Volume	*Range*	'less volume'; 'much volume'; 'the water rise more'; 'larger'; 'how big the object is'
	Medium	'the size of an object'; 'the volume'; 'size'
	Circumstance of Condition	'even if they are the same size'; 'if they were the same size'
Material/ characteristics	*Process/Range*	'didn't have (any) holes'; 'more compact'; 'more compacted'; 'a soliderfied liquid'; 'harder'; 'more durable'; 'made to withstand hitting other item'; 'soft'; 'easy to break'
	Circumstance of Reason	'because of the materials in it'

#Words in round brackets are our best guess of students' writings.

the same size'. Some clauses, such as 'the size does not matter', invoked volume as a *Medium* to explain the difference in density between the marble and the candle. These clauses appear to generalise the relationship between volume and density.

Submicro references. The main *Media* found in submicro references referred to submicro entities (e.g. 'particles'; 'molecules' and 'atoms'). The LG resources associated with these *Media* can be broadly clustered into those that are related to:

(1) quantity;
(2) packing or
(3) mass

As illustrated in Table 4, LG resources related to either the packing or quantity of the *Media* were employed as *Ranges* in some submicro references. Alternatively,

Table 4. Diversity of LG resources employed in the submicro references

Related to	Linguistic class	Instances
Quantity	*Medium*	'more'; 'more particles'; 'more particles within a certain area'; 'more molecules'; 'the more the atoms or particles'; 'less molecules'
	Range	'how many molecules'
Packing	*Process*	'packed'; 'compressed and connected to each other'; 'squished'; 'grouped together'; 'packed together'; 'packed very tightly'
	Range	'more compact'; 'closer together'; 'further away'; 'more compacted'; 'squashed together'; 'closer together'; 'further away'; 'how close'
Mass	*Range*	'heav[i]er'

these LG resources were also employed as a *Process* or as part of a *Medium*. As in the macro references, these LG resources often served as a standalone reason for the difference in density (i.e. without reference to other variables, particularly the volume). Only one student represented the mass of the *Media* by employing the *Range* ‘heavier’. The *Ranges* ‘compact’ and ‘heavier’ were found in both the macro references and the submicro references.

Diversity of meanings. Both the macro references and the submicro references contained a diversity of meanings. The first column in Table 5 outlined the different meaning categories found among the students’ explanation: 5 in macro references and 2 in submicro references. The second column shows an example of student’s explanation that illustrates the meaning category, while the third column provides additional information that clarifies how the meaning category was derived.

Comparison between the Students’ Writings and the Instructional Language

Having identified the diversity of LG resources and meanings from the students’ explanations, we next compared them with what could be found in the instructional language. The last column in Table 5 outlined the similarities and differences in the use of language between the students’ explanations and the instructional language. Of the differences, one of the most significant in relation to explaining the density difference is not qualifying the explanation in terms of mass of the objects as based on ‘per unit volume’ or ‘same volume of objects’. In a similar vein, some of the students’ explanations also did not qualify the comparison in terms of the number of the particles as based on ‘per unit volume’ or ‘same volume of objects’. However, these students did further qualify their explanation with the use of LG resources which implied more particles per unit volume, such as ‘compacted’, ‘packed very tightly’, ‘squished’, ‘squashed’, ‘grouped together’ and ‘compressed’.

Inferring Challenges Students Faced in Appropriating the Instructional Language

The diversity of meanings among the students’ explanations and their differences in comparison with the instructional language indicate that the students encountered much difficulty in appropriating the instructional language. This difficulty is reflected not only at a collective level but also within individual students’ explanations. Among the students’ explanations, Keith’s explanation was arguably the most consistent with the instructional language (see Figure 2).

Whenever Keith explained the difference in density between the marble and the candle in terms of the mass of objects or number of particles, he accompanied his explanation with the *Circumstance of Condition* ‘if they were the same size’. His diagrams also clearly made the comparison on the basis of equal volume. Unlike Keith, most other students’ explanations did not invoke the *Circumstance of Condition* ‘per

Table 5. Diversity of meaning in students' explanations and its comparison with the instructional language

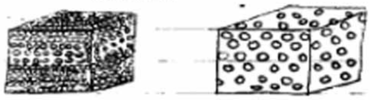
	Density difference explained in terms of	Example of student's explanation	Remark	Compared with instructional language
Macro references	A difference in mass per unit volume	'If they were the same size, the marble would weigh more and have more particles'	The qualification 'if they were the same size' appropriated the Circumstance *of Condition* 'per unit volume' that is necessary for the difference in mass to be sufficient to explain the difference in density	The meaning that the difference in density could be explained by a difference in mass between objects of equal size was similar to that realised through the instructional language (e.g. 'So even though they have the same volume, there is a hundred and forty gram difference.' [Teacher])
	A difference in mass	'The marble has more dense[sic] than the candle because the marble had a bigger mass'	Student's use of *Range* 'a bigger mass' was not coupled with any *Circumstance of Condition* involving volume	Unlike the instructional language which represented the difference in density as due to a difference in mass per unit volume, some students' written language did not qualify the comparison in mass as based on 'per unit volume' or 'same volume of objects'
	Volume as inversely proportional to density	'The marble is more dense, I think that, it is more dense because it has less volume'	Student's use of 'less volume' was not coupled with any *Circumstance of Condition* involving mass	Some students employed LG resources related to volume to realise the meaning that density was inversely proportional to volume, a meaning not expressed in the instructional language
	Size as not corresponding to density	'The volumn [sic] of the object is almost equally to the density. Thus, the size of an object doesn't matter	The student who wrote this statement elaborated what he meant by this statement during an interview: 'See the candle was larger, it was like around this big [gesturing the approximate size of candle with his fingers], and the marble this small, but still the marble is heav—have a greater density'. His elaboration suggested he had most likely intended the clause to imply that size does not correspond with density	Some students employed different LG resources to realise the same meaning as expressed in the instructional language: that bigger volume did not equate to greater density
	Materials/ characteristics of the objects	'The marble was much denser because it was harder, more durable … '	Density difference was explained in terms of the characteristics of the objects that are not related to its mass or volume	Though LG resources related to the materials could be found in the instructional language, they were not employed to explain density difference in the same way as in some students' explanations. Most of students' LG resources related to material or characteristic of objects were in fact not found in the instructional language.

Submicro references	a difference in number of particles per unit volume	'The particles are more compacted in the marble than in the candle'	Student's use of 'more compacted' implies that one object has more particles per unit volume than the other. The explanation 'If they were the same size, the marble would weigh more and have more particles', also implies similar meaning.	Similar LG resources (e.g. 'compact', 'packed very tightly') that represented the packing of particles were found in both the students' written language and the instructional language. The use of these LG resources implied more particles per unit volume. Additionally, students employed different LG resources to realise similar meaning expressed in the instructional language in relation to the packing of particles (e.g. 'squished', 'squashed', 'grouped together'; compressed').
	a difference in the number of particles	'The object that is more dense than the other is the marble & even though it is smaller than the candle it has more density because there are more particles or atoms inside the marble than the candle'	Student's explanation implies that one object has more particles than the other (without LG resources suggesting that the comparison was based on 'per unit volume' or 'same volume of objects')	Unlike the instructional language, some students' written language did not qualify the comparison in quantity of particles as based on 'per unit volume' or 'same volume of objects'

Object	Mass (g)	Initial volume of water, V_1 (mL)	Final volume of water, V_2 (mL)	Volume of object V_2-V_1	Density (g/cm^3)
Candle	6.7g	60mL	68mL	8mL	0.8cm^3
Marble	5.2g	60mL	62mL	2mL	2.6cm^3

Discussion:

1. The marble is more dense.
2. Using the particle theory we found out that if an object has more particles it will weigh heavier even if they are the same size. It just means that the particles are just more packed together, and there are many more making it heavier.



O= particles

Conclusion:

I learnt that size and weight would not contribute to being denser and that the two different objects were quite different but what surprised me would be that the marble is much denser than the candle.

Another reason why the marble was denser is because the marble had much more particles within a certain area than the candle. eg If they were the same size the marble would weigh more and have more particles.

Figure 2. Keith's explanation

unit volume' or 'if both objects have the same volume' when making similar comparisons. A closer look at his explanation, however, indicates that not every statements made by Keith was unambiguous in illustrating the meaning of density. For example, his statement 'size and weight would not contribute to being denser' made one wonders what he intended to mean with regard to the effects of size and weight in determining the density of an object. Taken with his other statements, the statement is likely to mean that an object may not necessarily be denser even if it has a bigger volume and mass (as in the case of his candle). Despite his clarity in explaining the difference in density in terms of mass and particle number both verbally and diagrammatically, Keith's explanation displayed some, albeit minor, difficulties in accounting for the density differences in an unambiguous way.

In comparison, the challenges faced by his peers were more pronounced. These include Lionel who paired up with Keith during the practical and hence shared the same experimental data (see Figure 3).

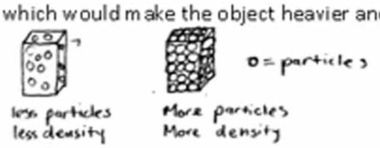
Lionel's diagrams construe the difference in density as due to the marble having more particles than the candle with the comparison made on the basis of equal volume. With regard to mass, his second statement under the discussion section alludes to a comparison on the basis of equal volume ('even if they are the same size'). This statement bares much similarity to Keith's same position statement under the discussion section, suggesting that the two students might have discussed with each other about their findings post-practical. However, his first statement did

Object	Mass (g)	Initial volume of water, V_1 (mL)	Final volume of water, V_2 (mL)	Volume of object $V_2 - V_1$ (cm^3)	Density (g/cm^3)
marble	5.2g	60ml	62 ml	2 ml	2.6 cm^3
candle	6.7g	60ml	68 ml	8 ml	0.8 cm^3

Discussion:

Q1 The candle had more density than the marble because there are more mass in the marble than the candle

Q2 We found out using the particle theory that if an object has more particles and will weight heavier even if they are the same size. It means the particles are more particles squashed together, which would make the object heavier and will sink.



Conclusion:

From out results that the candle was a larger heiver object than than the marble, but the marble which was a smaller lighter object had more density. That is because there are more particles are squashed into the marble than the candle.

Figure 3. Lionel's explanation

not display the need to make the comparison on the basis of equal volume. His first statement—denoting a higher mass in the marble—however contradicted his experimental data, which clearly indicated the candle as having a lower density despite having a higher mass and volume. This contradiction raises the question of what Lionel intended to mean with his first statement. Did he take for granted that the comparison was assuming equal size of both the candle and the marble? Similar contradiction could be found in two other students' explanations: both explained the difference in density as due to a higher mass in the denser object despite their experimental data indicating otherwise. These explanations, together with Keith's and Lionel's, suggest that the challenges these students encountered could be more representational than conceptual in nature.

There are other explanations that similarly displayed such inconsistent or ambiguous semantic patterns. An example is the use of the clause 'size does not matter'. This clause, employed in the written explanations of four students, resembles another statement written in Keith's explanation (i.e. 'size and weight would not contribute to being dense'). There are at least two possible interpretations of this clause: (1) size does not uniquely determine density; or (2) size does not determine the density at all. Additional data in the form of interview (see Table 5) were available from one student which suggested that he likely intended the first meaning. Unfortunately, it was less clear from the explanations alone what the other three students meant by the clause.

The association of the same word with both macro and submicro *Media* also created ambiguity in some students' explanations. For example, the word 'compact' was associated with only the submicro *Media* (e.g. 'atoms', 'particles') in the instructional language. This was unlike its association with macro *Media* (e.g. 'the marble is compacted') in the students' explanations. In the instructional language, the use of the word (as in 'How compact the atoms or particles are') suggests that the atoms or particles are tightly packed together. In the case of its association with a macro *Medium* such as 'the marble', it is less clear whether the student intended the same meaning as in the instructional language. Another example is the association of 'heavier' with a submicro *Medium* ('the particle in the marble are heaver [sic] than the ones in the candle'). This is again in contrast to the instructional language which associated mass only with macroscopic *Media*. Two interpretations are also possible with this statement: (1) individual particles in the marble are heavier than those in the candle; or (2) particles in the marble are collectively heavier than those in the candle. Given that only the mass of macroscopic entities was referred to in the context of the practical activity and that there was no prior instruction related to the properties of particles, the second meaning appeared to be the more likely one intended by the student. Nonetheless, we could not discount the possibility that the student might have invoked her prior knowledge about particles when constructing her explanation. Overall, the use of LG resources such as 'compact' and 'heavier' raises the question of whether students intended similar or different meanings when the same LG resources were associated with macro entities and with submicro entities. If it was the latter, it may not be valid to assume such use of LG resources as a failure to make the necessary ontological distinction between macroscopic and submicro entities (e.g. De Jong & Taber, 2007; Gilbert & Treagust, 2009), but more likely simply a case of indiscriminate use of LG resources (Seah et al., 2011).

In conclusion, our analysis of the students' writings indicates that at least some of the difficulties students had in communicating their learning, specifically in their written practical reports, could be representational in nature. Our inference does not negate the findings in Xu and Clarke (2012) that many of the students encountered conceptual challenges due to the ambiguities inherent in the classroom interactions. Our fine-grained examination of the students' writings using the SFL perspective, however, provides an additional dimension to the challenges encountered by the students in communicating their learning.

Discussion

Our analysis illustrates that a lack of awareness of the conventions and conditions in which the LG resources are employed could be one of the reasons for the students' difficulties in providing a scientific explanation for the density difference. For example, the meaning realised by some of the students would have been in line with the instructional language if these students had included in their explanations the *Circumstance of Condition* 'per unit volume' or 'if the volume of the objects are equal' when employing LG resources relating to quantity of particles (or mass of object). While this could conceivably be due to the construction of a 'misconception' that equates density with quantity of particles (or mass of objects), it could also be due to the students not equipped with the necessary semiotic tools (as reflected in Lionel's and several other explanations). There is also the possibility that the students might have simply taken for granted the need to explicate the basis for comparison in terms or per unit volume or same volume of objects. In fact, Snir (1991) noted that Archimedes himself employed the word *lighter* in his writings to mean 'a weight *less* than that of an object identical to it in shape (i.e. one with the same volume)' (original emphasis, p. 598).

In our earlier study (Seah et al., 2013), we invoked the notion of condition-of-use for LG resources (i.e. the circumstance or condition in which the LG resources are employed) as a significant aspect of language that students need to appropriate alongside the meaning of LG resources in order to employ these resources to realise meaning that is aligned with the scientific perspective. In this study, the meaning realised by the students would have been in line with the instructional language if these students had included in their explanations the *Circumstance of Condition* 'per unit volume' or 'if the volume of the objects are equal' when employing LG resources relating to quantity of particles (or mass of object). The *Circumstance of Condition* thus constitutes an important condition-of-use for these LG resources when employed to explain density differences. As with our previous study, the condition-of-use for LG resources were uncovered from the differences in the way LG resources were employed by students as compared to the instructional language. In so doing, the condition-of-use for LG resources takes into consideration how students tend to employ these LG resources and the way in which these LG resources are canonically employed in science, and addresses the gap between the two. We can thus learn much about students' challenges in appropriating the scientific language through examining the gap between how students tend to employ LG resources and the way these are used in science (just as we did from examining their alternative conceptions).

Further research could investigate the degree of consistency in the way students (at least of a particular culture) employ particular LG resources relevant to a topic.

Though the representational challenges identified in this study were revealed mainly through a comparison of the students' writings and the instructional language, we do not assume that the latter was the only source of LG resources for the former. There was of course the likelihood that the students' writings could be contingently produced, based on snippets on what they could catch during the lesson or from their peers and whatever they remembered from their past encounters with the topic. Nonetheless, the comparison highlights the representational gaps that students need to transverse if they were to employ the relevant LG resources in a scientifically appropriate way, especially when the context of comparison changes.

Having identified the condition-of-use that the students failed to appropriate, we further examined the whole-class instruction to postulate why this was so. First, although the teacher had emphasised that the volume remained constant when comparing the lead block and the aluminium block used in the teacher demonstration, he did not discuss the rationale for holding the volume constant in the demonstration and allowing it to vary subsequently during the practical activity. This might have contributed to some students employing LG resources the same way as during the demonstration where there was limited reference to the volume (e.g. when the teacher asked 'lead is denser because it has?', the accepted replies from the students were 'more mass' and 'more particles contained in it'). Such indiscriminate use of LG resources might have been avoided if the teacher had asked 'What is the difference between comparing the two metal blocks and comparing the marble and the candle?'. This could be further followed up by 'Would the difference in volume between the candle and marble play a role in explaining the difference in their density, and why?'. This might have engaged the students into thinking the role that volume played in both contexts.

Second, the students had limited opportunity during instruction to practise providing explanations for differences in density. The only occasion from which the students could appropriate any sort of explanation was the teacher demonstration, after which the students were expected to make use of the same explanation in a different context where the two objects being compared were of unequal mass and volume. There was no prior discussion about objects of unequal volume prior to the practical. Such a discussion would have provided a linguistic 'model' illustrating the use of LG resources in a new context. In particular, the discussion would likely have highlighted the significance of the condition-of-use for those LG resources relating to the quantity of particles and the mass of object. Such a discussion would also provide the teacher with greater opportunity to assess students' understanding and their ability to represent their meaning accurately. Third, the opportunity to assess students' ability was also further constrained by the limited length of the students' responses during the whole-class discussion. Consistently encouraging students to elaborate their responses (instead of providing short phrases) would not only provide more opportunities for students to rehearse their use of the scientific language but also indicate their ability to do so. Last but not least, in the two lessons on density, the students were also not exposed to any scientific text besides the practical worksheet. The provision of scientific texts would provide another model from which the students could appropriate the scientific way of using the relevant LG resources (Fang & Wei, 2010). While no direct cause-and-effect relationship can be established between the instructional language used in this lesson and the students' writings, the whole enterprise of teaching science hinges on the basis that that instructional language significantly influences students' use of language. Links such as those identified here provide valuable insights into how we might more effectively promote students' appropriation and employment of the language of school science.

This study highlights several specific points within the whole-class instruction that the teacher could have further supported students in acquiring a more sophisticated use of the relevant LG resources—by making explicit the condition-of-use for the relevant LG resources. In Xu and Clarke's (2012) paper, their recommendations for the instruction on density have focused on establishing a common understanding among the teacher and students, such as through the explicit reference to the notion of substance so as to provide 'a conceptual connection between microscopic and macroscopic properties' (p. 788). The analysis of the same data-set from the language perspective, however, suggests that facilitating a common understanding may not be sufficient in ensuring that students have the semiotic tools to represent their understanding. Learning the language of science demands more than learning its meaning but entails the control of the use of its constituting LG resources. Such control would in turn require knowledge of the conditions and circumstances of when to use them (condition-of-use); how to put them together (the structural features of the relevant genres of science); the differences between the different ways of putting them together (e.g. differences between oral language and written language and differences between everyday language and the language of school science) (Seah et al., 2013). Our analysis suggests that much can be done at the classroom discourse level to foster students' ability to explain density differences. To a certain extent, our suggestions are in line with and complemented that advocated by Kloos et al. (2010, p. 635), who argued for 'the importance of a scaffolded structure in the learning environment' to foster students' competent performance in density tasks. However, our suggestions for pedagogical intervention differ from the existing literature in that emphasis is placed not only on the conceptual aspect of learning density but also on the linguistic means for realising scientific meaning related to density. We believe such an approach has the added advantage of fostering the fundamental literacy aspect of science education besides the derived literacy (Norris & Phillips, 2003). Such an approach can be integrated with those suggested by the existing literatures (e.g. Smith et al., 1997; Xu & Clarke, 2012) to strengthen students' learning of density.

Concluding remarks

By taking a language perspective, this study has shown that the challenges students are likely to encounter in learning density are not confined to its conceptual demands but include the representational demands embodied in the use of scientific language. To better equipped teachers in taking a more balanced approach towards addressing both the conceptual and linguistic challenges of science learning, this study suggests that there is a need to include not just content but also language objectives when developing curriculum. For example, the condition-of-use of certain LG resources that tends to be neglected by students can be highlighted in syllabus or curriculum materials that teachers refer to so as to alert them to these potential linguistic challenges. Raising awareness of these challenges and the possible strategies for overcoming them through further professional development is also necessary to equip teachers with the skills and confidence level in addressing these challenges in the classrooms.

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Note

1. As in the study by Smith et al. (1997), the concepts of weight and mass are not differentiated for the purpose of this study as it was not an instructional goal of the teacher in our case study.

References

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

Dawson, C. J. (1981). Volume and density: How much do students really understand? Some effects of an ASEP unit at year 9 level. *Australian Science Teachers Journal, 27*(3), 75–82.

De Jong, O., & Taber, K. S. (2007). Teaching and learning the many faces of chemistry. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 631–652). Mahwah, NJ: Lawrence Erlbaum Associates.

Eisenhart, M. (2006). Representing qualitative data. In J. L. Green, G. Camilli, P. B. Elmore, A. Skukauskaite & E. Grace (Eds.), *Handbook of complementary methods in education research* (pp. 567–581). Mahwah, NJ: American Educational Research Association; Lawrence Erlbaum Associates Publishers.

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

Fang, Z. H. (2006). The language demands of science reading in middle school. *International Journal of Science Education, 28*(5), 491–520.

Fang, Z. H., & Wei, Y. (2010). Improving middle school students' science literacy through reading infusion. *Journal of Educational Research, 103*(4), 262–273.

Fassoulopoulos, G., Kariotoglou, P., & Koumaras, P. (2003). Consistent and inconsistent pupils' reasoning about intensive quantities: The case of density and pressure. *Research in Science Education, 33*(1), 71–87. doi:10.1023/A:1023658419034

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

Gilbert, J., & Treagust, D. F. (2009). *Multiple representations in chemical education*. Dordrecht: Springer.

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

Halliday, M. A. K. (1994). An introduction to functional grammar (2nd ed.). London: Edward Arnold.

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

Halliday, M. A. K., & Martin, J. R. (1993). *Writing science: Literacy and discursive power*. London: Falmer Press.

Hewson, M. G. (1986). The acquisition of scientific knowledge: Analysis and representation of student conceptions concerning density. *Science Education*, 70(2), 159–170.

Hewson, M. G., & Hewson, P. W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies in science learning. *Journal of Research in Science Teaching, 20*(8), 731–743.

Jaipal, K. (2010). Meaning making through multiple modalities in a biology classroom: A multimodal semiotics discourse analysis. *Science Education, 94*, 48–72.

Johnson, P., & Papageorgiou, G. (2010). Rethinking the introduction of Particle Theory: A substance-based framework. *Journal of Research in Science Teaching, 47*(2), 130–150.

Kloos, H., Fisher, A., & Van Orden, G. C. (2010). Situated naïve physics: Task constraints decide what children know about density. *Journal of Experimental Psychology: General, 139*(4), 625–637.

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

Lemke, J. L. (1998). Analysing verbal data: Priniciples, methods and problems. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (Vol. 2, pp. 1175–1189). Dordrecht, The Netherlands: Kluwer Academic Publishers BV.

Leont'ev, A. N. (1981). The problem of activity in psychology (J. V. Wertsch, Trans.). In J. V. Wertsch (Ed.), *The concept of activity in soviet psychology* (2nd ed., pp. 37–71). New York: ME Sharpe (Reprinted from: 1981).

Márquez, C., Izquierdo, M., & Espinet, M. (2006). Multimodal science teachers' discourse in modeling the water cycle. *Science Education, 90*, 202–226.

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

Pines, A. L., & West, L. H. T. (1986). Conceptual understanding and science learning: An interpretation of research within a sources-of-knowledge framework. *Science Education, 70*(5), 583–604.

Seah, L. H., Clarke, D. J., & Hart, C. E. (2011). Understanding students' language use about expansion through analyzing their lexicogrammatical resources. *Science Education, 95*(5), 852–876. doi:10.1002/sce.20448

Seah, L. H., Clarke, D. J., & Hart, C. E. (2013). Understanding the Language Demands on Science Students from an Integrated Science and Language Perspective. *International Journal of Science Education, 36*(6), 952–973. doi:10.1080/09500693.2013.832003

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

Smith, C., Carey, S., Wiser, M. (1985). On differentiation: A case study of the development of the concepts of size, weight and density. *Cognition, 21*(3), 177–237.

Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' preinstruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction, 15*(3), 317–393.

Snir, J. (1991). Sink or float—What do the experts think?: The historical development of explanations for floatation. *Science Education, 75*(5), 595–609.

Thörne, K., & Gericke, N. (2014). Teaching genetics in secondary classrooms: A linguistic analysis of teachers' talk about proteins. *Research in Science Education, 44*(1), 81–108. doi:10.1007/s11165-013-9375-9

Veel, R. (1997). Learning how to mean—scientific speaking: Apprenticeship into scientific discourse in the secondary school. In F. Christie & J. R. Martin (Eds.), *Genre and institutions: Social processes in the workplace and school* (pp. 161–194). London: Cassell.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

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

Xu, L., & Clarke, D. (2012). Student difficulties in learning density: A distributed cognition perspective. *Research in Science Education, 42*, 769–789.