Title	What student language reveals about the demands of learning the human circulatory system
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Abstract

This study examined student language in learning the human circulatory system, to understand the challenges they face in representing the knowledge in this topic. Data for this study comprised students' written responses to a range of structured test items. Responses to 17 test items from 70 students across four classes were analysed using tools adapted from the Systemic Functional Linguistics framework using the seven categories of: Process error, Participant error, Descriptor error, Circumstance error, Connective error, Missing word and Irrelevant word. The analysis revealed six problems in language use that occurred in all four classes taught by three different teachers. Students in the study encountered most difficulties with the use of Participants. Reasons for the prevalence of this error type are proposed. The problematic nature of student language use is discussed in relation to both the conceptual demands inherent in the topic and the scientific practice of language generation in science. Examining the student language illuminates the need for students to understand the rationale for the finely distinguished terminology found in this topic.

Keywords: Human Circulatory System, learning demands, student language, Systemic Functional Linguistics

What Student Language Reveals about the Demands of Learning the Human Circulatory System

Introduction

The Human Circulatory System (HCS) is an important and challenging topic in the learning of biology. While many studies have investigated the conceptual difficulties faced by learners in this topic (e.g., Arnaudin and Mintzes 1985; Bahar, Ozel, Provok and Usak 2008; Cheng and Gilbert 2015; Chi, Chiu and deLeeuw 1991), none have analysed students' language difficulties. As Halliday and Martin (1993) and Wellington and Osborne (2001) have established, language can be a barrier in science learning and learning the language itself is considered a major achievement of science learning. This paper will show how the analysis of student language use can shed light on the demands of learning about the HCS, beyond the difficulties associated with its conceptual demands.

Yore and Treagust (2006) proposed the notion of the three-language problem to underscore the different discourse communities and hence languages (home, instructional and science) that a student encounters in a science classroom. As these languages serve different contexts and purposes, they embody within them different terminologies, language features and norms (Halliday, 2004). Science, for example, involves the learning of both technical and non-technical components of its language. In addition to technical terms, students also encounter everyday terms with distinct meaning, logical connectives (e.g., because, therefore) and metarepresentational terms (e.g., explain, hypothesize) (Oyoo, 2017). If students are to participate effectively in a community of science learners, they need to master the linguistic resources, structures and conventions that scientists develop to generate and transmit scientific theories, principles and practices (Fang 2005). Learning science thus involves learning a new way of using words akin to learning a new language, something that requires explicit instruction (Brown and Ryoo, 2008).

A language perspective is especially relevant to HCS given the high volume of technical terms that students need to learn to access the content. A count of the terms that can be found in the Index at the back of the school textbook (Lam and Lam, 2013) used by the participants in this study revealed a total of 85 terms (e.g., pericardium, phagocytosis, pulmonary circulation, thrombokinase) within the HCS chapter. Taking a functional-semantic perspective of language as an analytical lens, this study examined student writing to understand how students use language differently from the established ways of representing HCS. In this view, language plays a functional (as opposed to arbitrary) role in constructing scientific meaning (Halliday 2004). This means that comparing the ways that students use language to represent their understanding with the ways that scientific knowledge is normatively represented can shed light on the linguistic challenges students face when encountering a topic such as HCS. This study made use of student responses to test items completed after studying the topic HCS, in order to make such comparisons. From these responses, language-related errors that were common across several classes were identified. To identify ways that instruction might have aided student learning or contributed to the students' language-related errors, teacher talk related to the language use pertaining to these errors were also examined. The two research questions that guided this study are:

1. What language errors did students make in their written responses?
2. In what ways did the teachers address the language issues related to these errors during whole-class talk?

Background

The HCS was cited as among the top five most important biology topics that students need to learn (Chi et al. 1991). The concepts in this topic provide the foundation for learning other biological concepts and topics such as transport and exchange of materials in the human body, the respiratory and the lymphatic systems (Cheng and Gilbert 2015). Studies have found that students across various grade levels (5th, 8th and 10th grades students as well as college freshmen in the case of Arnaudin and Mintzes 1985; and 5th and 7th grade students and 1st and 4th year undergraduates in the case of Özgür 2013) displayed persistent misconceptions in the topic across multiple concepts. These misconceptions may encompass everything from the functions of the heart to the ways that blood circulates around the body (Özgür 2013). Such misconceptions can impede students' abilities to advance their knowledge and understandings of the topic. Several reasons or sources of student misconceptions have been proposed. These include: (1) insufficient knowledge; (2) not easily perceptible entities within the system; (3) the complex processes involved including circulation (Chi et al. 1991); (4) difficulties in integrating the information coded in the different forms of representations (Cheng and Gilbert 2015); (5) classroom instruction that fails to take into account students' alternative conceptions (Mintzes 1989); and (6) misinterpretations of the textbook (Özgür 2013). Language demands in learning about the HCS have not been analysed, except in Pelaez, Boyd, Rojas and Hoover (2005). Their study highlighted the imprecise use of language, including the use of terms such as circulation, vein and exchange, as a source of errors made by their undergraduate trainee elementary teachers. In spite of the widely acknowledged need to attend to language issues in the learning of science content (Brown and Ryoo, 2008; González-Howard, McNeill, Marco-Bujosa and Proctor, 2017; Lee, Quinn and Valdés, 2013), it appears that language as a potential source of difficulties in understanding and representing the HCS has not been given much attention.

Language Demands of Science Learning

Wellington and Osborne (2001) asserted that language is the 'greatest obstacle in learning science' and that for students 'the most important achievement—is to learn its language' (p. 3). Such emphasis on the role of language in science learning reflects the sociocultural turn in research over the past few decades. Language serves multiple functions in science classrooms, since it is a system:

(1) for communicating knowledge, (2) for interpreting experience, and (3) for participating in the discursive communities (Carlsen 2007). Hence, in addition to its apparent communicative and rhetorical role, language also serves as an epistemic tool for developing a scientific consciousness and world-view (Veel 1993).

A language-based perspective on learning, which assumes that learning involves not just learning through language, but also learning of and about language (Halliday 1993) offers valuable insights for supporting science learning. From a disciplinary perspective, science learning entails not just learning scientific language, it also entails learning *about* scientific language. The importance of learning about scientific language is supported by two bodies of research: research on disciplinary literacy (Green and Lambert 2018; Shanahan and Shanahan 2008); and, research on the distinctive uses of scientific language from a functional perspective (Halliday and Martin 1993; Fang 2005; Schleppegrell 2004).

‘Disciplinary literacy’ has been described as both a goal of science education and a pedagogical approach. As a goal, disciplinary literacy refers to ‘the ability to engage in social, semiotic, and cognitive practices consistent with those of content experts’ (Fang 2012, p. 19). Disciplinary literacy is thus viewed as an additional skillset beyond general academic proficiency (Shanahan and Shanahan 2008). As a pedagogical approach, it advocates the importance of more explicit teaching of disciplinary language and literacy practices (see for example, Fang and Coatoam 2013). Disciplinary literacy highlights the differences between disciplines by drawing attention to the manner in which content is constructed, represented and evaluated (Fang 2012). This has led to comparative research on the literacy practices of expert readers across disciplines. For example, Shanahan, Shanahan and Misischia (2011) highlighted disciplinary differences in the reading strategies of experts in history, chemistry and mathematics, such as in the criteria used for sourcing texts, methods of corroborating meaning from multiple texts and of interpreting the representations embedded within the texts.

Systemic Functional Linguistics (SFL), which seeks to link the linguistic resources to the social and cultural settings in which the resources are used (Halliday and Matthiessen 2004), provides a specific tool for analysing language from a functional point of view. Such analysis is critical for revealing aspects of language that are distinctive and consequential in science. For example, Fang (2006) identified several features of language found in secondary science textbooks, which could hamper student understanding. These features include use of long noun phrases and complex sentences, the unique ways grammatical resources such as conjunctions and prepositions are used and a preference for passive voice. At the text level, Veel (1997) identified the roles that particular language features play in constructing various genres of science texts (e.g., sequential explanation, causal explanation, practical report). This body of research advocated making explicit the form-function relation of language, so as to support students' learning of the content of science through developing their appreciation of how scientific language is constituted and how it functions differently from everyday language (Fang 2012).

Scientific language and science literacy practices differ from that of other contexts and disciplines in ways that reflect the distinctive conventions, norms and practices of the scientific discipline. Scientific language emerges and evolves to cater to the demands of the scientific enterprise (Halliday 2004). Learning these differences thus constitutes learning about scientific language *and* learning about science content and its practices. Not making these language differences explicit runs the risk of alienating students who may find scientific language difficult and exclusive (Fang 2005). Halliday (2004) proposed that:

> children can be helped quite considerably if they are explicitly taught about the nature of technical and scientific language, including both its generic structures and

> its grammatical structures, at the same time as they are engaging with the scientific disciplines themselves. This as it were lets them into the secret, and helps them understand why they are faced with all these new and exotic ways of meaning. (p. 198)

As students are new to the disciplinary language, they tend to use language that does not mirror the conventions and norms of the discipline (Author et al. 2011). Their language use thus provides a means for revealing critical aspects of scientific language that are neglected in science instruction.

Numerous studies have examined the distinctive language patterns and demands of science learning that are generic to the discipline (e.g., Fang 2005; Halliday 2004; Halliday and Martin 1993; Veel 1997). Although knowledge of these language demands can inform science instruction, their classroom implications may not be accessible to teachers with limited linguistic knowledge and interests (Cammarata and Tedick 2012; Morton 2016). In view of this, teachers can be helped to understand how topic-associated language demands interact with students' alternative conceptions. Both considerations are important for better-informed instructional design. However, apart from Author et al. (2015), Frändberg, Lincoln, and Wallin (2013) and Thörne and Gericke (2014), there have been relatively few studies on the language demands students encounter at the topic level. By contrast, there is a large body of research within the conceptual change paradigm, exploring students' alternative conceptions in a wide range of topics (Liu, 2001). Consequently, although understanding student language use at the topic-level is just as important as understanding students' prior conceptions, teachers may be less aware of topic-level language demands as this aspect of science instruction is under-researched.

The premises and research gaps identified in the above review of existing studies provided the impetus for this study. By examining student language use in learning about the HCS, this study sought to uncover the language demands of learning HCS and aspects of science practices neglected in instruction.

Language and Science Practices

Scientific practices have gained increased attention in recent years, as seen in the Next Generation Science Standards (NGSS), a project coordinated by Achieve, Inc (2013). Much of the focus on language-related scientific practices has been on constructing explanations, engaging in arguments and communicating information, practices which result in the production of scientific texts in the form of propositions and theories. However, little attention has been paid to scientific practices that result in the production of the 'complex lexical taxonomy'[1] (cf. Halliday 2004, p. 151) characteristic of scientific language, despite its importance in understanding the nature of science. This is especially relevant if we accept that scientific language evolves from everyday language in ways that meet the specific needs of scientists to represent scientific knowledge (Halliday 2004). A focus on the relations between scientific practices and the development of scientific language can point to ways for improving science instruction as the findings of this study suggest.

Research Design

Context of Study

This study was conducted in a co-educational government secondary school in Singapore. The four classes of Grade 9 students (age 15 years old), ranging in size from 13-20, were taught by three teachers. All participants, as well as the students' parents, gave consent in writing, as required by the university's research ethics approval process. All classes comprised students with varied abilities in biology, although students in Classes A and B were perceived by the three teachers to be

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[1] By 'complex lexical taxonomy', Halliday (2004) referred to the highly classified and/or hierarchical body of technical terms that are systematically built up to form a branch of science. For example, in the field of electricity, the terms involved would include electricity, electric circuit, conductor of electricity etc.

better performers than those in Classes C and D. This perception could largely be attributed to the students' science performance when they were in their lower grade. The students came from a range of ethnic and linguistic backgrounds, such as Chinese, Malay and Indian. Although English is the language of instruction, not all students speak English at home. To better understand the language profiles of the students, a survey, using both 5-point scale and open-ended items, was developed by the research team and conducted at the start of the study to capture the students' perceptions of their language abilities. Sixty-five of 70 students completed a language survey (93% response rate). Students reported varying confidence in English language proficiency. When asked about their abilities in writing responses to biology questions, nearly all the students (97%) reported having difficulties. 9% reported having difficulties 'very often', 23% 'half of the time' and 65% 'sometimes'. 93% of the students reported difficulties at some points with phrasing an answer to a biology question even when they understood the content: 5% reported encountering difficulties 'always', 15% 'very often', 15% 'half the time', and 58% 'sometimes'.

Although all the teachers had prior experience in teaching the HCS, their years of teaching experience varied widely. T1, who taught two classes (Class A [20 students] and Class B [14 students]) was in her fifth year of teaching; T2, who taught Class C [16 students], was in his first year; and T3, who taught Class D [20 students], was in his ninth year. As is typical of teacher preparation for teachers of specific disciplines (Bunch, 2013), the teachers had received limited (if any) preparation related to language issues in the teaching of science prior to participating in this project. During the study, the teachers worked with the research team to better understand the language challenges likely to be encountered by students in the topic of HCS. Except for one specific language-based activity implemented in each class, the teachers taught the rest of the lessons as they deemed fit. More details about how these teachers conducted these HCS lessons as well as the student survey results can be found in an earlier study (Author et al., 2018).

Data generation and analysis

For the topic on the HCS, the students learned five sub-topics based on their syllabus (in the following order: (1) blood components and their functions; (2) structures and functions of blood vessels; (3) structures and functions of heart structures; (4) the cardiac cycle; and (5) heart diseases. The present study was confined to only sub-topics (2) – (4). The entire topic was taught over a range of 12-14 lessons per class, with each lesson lasting between 30-60 min. All the lessons were recorded using a video-camera mounted on a tripod placed at the back of the classroom and connected to a wireless mike attached to the teacher.

The student data for the study came from two tests, which the teachers conducted a few weeks apart. In the first test (sub-topic 2), there were 10 structured questions which required students to respond beyond the phrase level. In the second test (sub-topics 3 and 4), there were seven items of a similar nature. The tests were developed through extended discussion between the researcher and the teachers. The items, adapted from an existing stock of test papers, were considered to have a high likelihood of revealing students' errors that reflect language use as opposed to misconceptions. The two test papers from a total of 70 students were analysed.

To address the first research question, each student's response was subjected to the following analysis:

1. Error analysis: the student's response was first compared with the expected answer. The part/s of the response, which differed in meaning from the expected, were identified and underlined.
2. Linguistic analysis: the errors identified were then coded with analytical categories adapted from Systemic Functional Linguistics (SFL) framework (Halliday and Matthiessen 2004) (see Table 1). These categories differentiated the errors according to the types of linguistic components which the erroneous word/phrase belongs to.

[Insert Table 1 here]

To identify errors at the word level required certain responses to be excluded from the linguistic analysis. Two types of answers were excluded: (1) answers that did not address the question (probably due to misunderstanding the question), (2) answers that were entirely different from the expected answer (probably due to a misconception). With these answers, it would be meaningless to subject them to linguistic analysis, as any inaccuracies that the students might have had in constructing these answers were not likely to be due to their choice of language.

The entire data set was coded by two coders who achieved an average of 87.6% agreement rate across the classes and tests. Any disagreement in the coding were resolved through discussion between the two coders. Within each test item, errors that were made by at least one student in each of the four classes, that is, those that were persistent across classes, were selected. Such errors were selected as they appeared to prevail regardless of the teacher and their instructional approaches.

Errors were further characterised based on three dimensions: accuracy, appropriateness and specificity as follows:

- Accuracy: when the error was due to choice of language that is scientifically inaccurate, the error was characterised as ‘inaccurate’. An example is to describe ‘capillaries’ as one cell thick instead of ‘capillary walls’.
- Appropriateness: when the choice of language use was not suitable for use in the context, even though it may not be inaccurate, the error was characterised as ‘inappropriate’. An example is the use of word ‘thin’ to describe the lumen of a blood vessel instead of small or narrow.
- Specificity: when language used failed to identify a clearly defined entity, such as an object, a concept, a process, the error was characterised as ‘non-specific’. An example is not specifying exactly which valve is closed or open when describing the cardiac cycle.

Characterising the errors based on these three dimensions relates the language used to the scientific meaning represented and differentiated the errors according to their impact on the overall status of the students' answers with respect to the expected answers.

To address the second research question, 39 lesson videos on the entire topic from three classes were analysed. A two-phase analysis was conducted on the videos. In the first phase, the lesson videos were analysed to identify episodes in which the teachers *foregrounded* aspects of the language relevant to the topic. 'Foregrounding' here refers to any 'discursive act that indicates linguistic prominence, emphasis and priority that supports students in their engagement, use or performance of language tasks' (Author et al 2017, p. 136). As the same teacher taught two of the classes, analysing the lessons from one of these classes was deemed adequate to provide the necessary insights on the ways in which this teacher addressed the language issues. The identified episodes were transcribed. These episodes revealed the words, sentences and texts, which the teachers foregrounded and talked about as well as the purposes of their talk. The second phase involved reviewing the transcribed episodes to look for those that might be relevant to the errors identified from the students' responses. These instances will be described to illustrate how the teachers attempted to address the language issues related to the students' errors.

Findings

A total of six errors across six test items were found to be present in the responses of students from *all* the four classes; these are shown in Table 2.

[Insert Table 2 here]

For each of the six test items, Table 2 shows the question stem, the categories of the errors (see Table 1) found in the students' responses to the item, together with an instance of each category of error. Each item is also represented by an abbreviation in the first column. To better illustrate the errors as they appeared in context, examples of students' responses are provided in the last column.

Table 3 presents the relative prevalence of these errors across the four classes.

[Insert Table 3 here]

As with Table 2, the first column of Table 3 identifies the item. The categories of error found in the students' responses for each item are displayed in the second column, while the next four columns display the percentage of the errors for each class. Finally, the last column presents the percentages of the students in the entire cohort whose responses contained the errors. In the following sections, the various types of errors will be described with reference to Tables 2 and 3. In addition, how the teachers had attempted to address the language issues related to these errors are also outlined.

Use of ***Participant***

The most prevalent category of error occurred with the use of *Participant*, occurring in two test items: BV_Q3b and HS_Q2b (see Table 2). Among the 21 students who made an error with the *Participant* in item Q3b, the majority (10) inaccurately identified capillaries as one-cell thick. By contrast, 'one cell thick' was used to characterise the capillary *walls* in the lessons. There was an instance when one teacher in Class B questioned the students by asking 'Capillary is one cell thick?'. When several students replied 'Walls', the teacher affirmed their answer by repeating 'The capillary *wall* is one-cell thick'. There was no episode in the other two classes where the teachers were observed to have explicitly differentiated between the capillary and the capillary wall with reference to this feature. Interestingly, no students in Class B identified capillary as being one-cell thick, but five students in Classes C and D did. As the video of Class A was not analysed, it is not known whether the same teacher made a similar clarification for Class A. However, five students in Class A also made this error, which suggests that even if the teacher did make the distinction, the students did not in their test responses.

This error can be characterised as either being inaccurate (for having incorrectly identified the specific structure – the capillary itself versus the capillary wall) or non-specific (lack of precision in identifying the capillary wall, not the capillary itself, as being one-cell thick). In the former case, one would presume that the students did not have a clear understanding of the relative size of capillaries compared to cells. With the latter, one could surmise that students might not perceive the need to be specific about what particular aspect of the capillary they are describing. Implications of both assumptions will be discussed later.

Other problems relating to *Participant*s included the use of pronouns as '*Participant*' or missing the referent entirely (8 instances). In both cases, it was not clear whether the students were referring to the vein or the capillary, or some specific aspect of either. Three students described the capillaries as having a membrane that is one-cell thick rather than one-cell thick wall. The inaccurate use of the *Participant* 'membrane' suggests that the students might not have understood the structure of the capillaries or they could have taken the walls of capillaries to be equivalent to a cell membrane in that both are barriers through which certain substances can pass.

In Item HS_Q2b, one problem was the use of non-specific *Participant*s (found in 13 responses). Some students did not seem to see the need to specify which valve needs to close during the ventricular systole stage of the cardiac cycle. Such answers are ambiguous, since there are multiple valves within the heart that could be closed or open at different stages of the cardiac cycle. While the teachers in general were rather specific in identifying specific valves when explaining the cardiac cycle to students, it seems that these students did not register the need to do so themselves. Alternatively, it could be that the students were unable to recall the specific valve that was involved during ventricular systole and hence left it unspecified.

Within the same item, another problem, the inaccurate use of *Participant*, occurred when the students mixed-up different heart structures (in 15 responses, with two responses showing both non-specific and inaccurate *Participant*). These errors included confusion between atrium and ventricle, right and left sides of the heart and between aorta and pulmonary artery or vein, and between bicuspid valve and tricuspid valve. Given the sheer volume of terminology, especially those related to the structures within the HCS, such errors would not be surprising. Nonetheless, it is still intriguing as to what could have contributed to this type of error: a case of memory confusion or a lack of understanding of the cardiac cycle.

Use of ***Process***

All the problematic uses of *Process* have to do with either the inappropriate or the inaccurate use of verbs to describe the action of muscles in students' responses to item BV_Q1d (see Table 2 for the question). A variety of verbs were employed (e.g., constricts, expands, weakens, increase in size, tightens, become bigger, decrease in size, narrower, wider, thinner, forced to squeeze closer), illustrating the students' attempts to make sense of how muscles work. For the HCS topic, students were required only to know the role of the muscles in relation to the flow of blood in either the blood vessels or the heart, but not the mechanism by which muscles work. With respect to the test item, the students were expected to state that 'the muscles contract'. The use of inappropriate *Processes* such as constricts, tightens, decrease in size, narrower, forced to squeeze closer, suggests that the students were not lacking in understanding of how the muscles would respond during arterial constriction as all these *Processes* suggest a reduction in size as a muscle contracts. Rather, such use suggests that these students were unaware of the appropriate language to describe how muscles work (untaught content) resulting in them using linguistic resources that are generally not associated with muscles. By contrast, those students who used *Processes* that suggest a meaning opposite to 'contract' (e.g., expands; increase in size; become bigger; wider) displayed a lack of understanding demanded by the test item.

All the teachers, except for one, had used contract and relax consistently to describe the action of muscles. In fact, one teacher explicitly made known to the students that they 'must use the word contract because muscle can only contract or relax'. Despite this, five out of her fourteen students in that class did not use this term. One teacher inadvertently associated the word ‘constrict’ with muscle on one occasion. Ironically, none of his students made the same error in their test responses, but at least four students in the classes taught by the other two teachers did.

Use of *Descriptor*

The problematic use of *Descriptor* has to do mainly with students’ use of inappropriate adjectives to describe the lumen (the space inside the blood vessels) in Item BV_Q1a. The question required students to recognise that the adjective ‘thick’ is both an inappropriate and inaccurate (entirely wrong meaning) word to describe the lumen (see Table 2). In their responses, eighteen students replaced ‘thick’ with ‘thin’, instead of the more appropriate word ‘small’, thus recognising the inaccuracy of ‘thick’ but not its inappropriateness. One student recognised the inappropriateness of ‘thick’ but not its inaccuracy, and replaced it with ‘large’, while six students did not recognise either aspect of the word. The question also required students to recognise that ‘deoxydised’ blood was both an inaccurate and inappropriate word to describe the content of arteries. Only one student failed to do so.

All three teachers had recognised students’ tendency to use the phrase ‘thin lumen’, and there were episodes in the discourse of each of the three classes analysed where the teachers specifically discussed why this use was inappropriate. For example, the teacher in Class D said:

> I think you have a misconception that the lumen is the wall. All of you have a very different idea of what a lumen is. Lumen is a space. So a space can be big, small but cannot be thin or thick. When you say thick you are referring to the wall.

Nonetheless, twelve out of twenty students in that class continued to describe lumen as thin.

Close to one third of the students used *Descriptors* that were not specific in responding to the test item BV_Q1b, which required them to compare among three types of blood vessels (see Table 2). Instead of using superlatives (e.g., highest, lowest) expected of, the majority of these students (18) used words such as high/low, very high such as in ‘The amount of blood pressure found in the arteriole and capillary is low while the blood pressure in the arteries is high.’ Though not necessarily inaccurate, not using superlatives indicates that blood vessel types were being described in absolute rather than comparative terms. This use of *Descriptors* such as ‘high’ or ‘very high’ mirrored the language the teachers had used to describe the blood pressure in the various blood vessel types. Consequently, it is unsurprising that the students did not use the more appropriate comparative terms ‘highest’ and ‘lowest’.

Four other students used ‘higher’ to compare one blood vessel type to the other two without making further comparison between the other two (e.g., ‘An artery has higher blood pressure than a capillary and arteriole.’). Their responses could mean that they might not know the difference between the two others, might not see the need to make the distinction, or were not equipped linguistically to compare beyond two entities. One student attempted to use a superlative but used an inappropriate one (lessest) to describe the blood pressure of capillaries in relation to the other blood vessel types.

Use of *Circumstance*

The occurrence of inaccurate and/or non-specific use of *Circumstances* took place in the students’ responses to the test item HS_Q3 (see Table 2). The problematic *Circumstances* were related to the description of the location of the tricuspid valve. Eight of the students provided non-specific *Circumstances* by merely identifying the side of the heart where the valve is found rather than its specific location between the right atrium and the right ventricle of the heart. Four students provided inaccurate *Circumstances* by citing the location of the valve as ‘between the right atrium and left atrium’, ‘between the atrium and the left ventricle’, ‘between right and left atrium and ventricle’ and ‘between the pulmonary vein and right atrium’. Two other students provided both non-specific and inaccurate *Circumstances* by simply identifying the location of the valve as on ‘the left side of the heart'. The lack of specificity in the description of the valve suggests either a lack of knowledge of its specific location or a lack of understanding why location needs to be identified in relation to its function.

Though all teachers had specified where tricuspid valve can be found and its function in this specific location, they did not explicitly discuss the significance of the valve location and the need to be precise in describing its location.

Distribution of errors across classes

As reflected in Table 3, there was no clear trend in the distribution of errors across classes. Some classes tended to have a much higher percentage of certain errors. It is important to note that the percentage and distribution of such errors may not be indicative of the overall language abilities of students as the absence of these errors might simply be a result of students not responding to the questions sufficiently for such errors to be detected in the first place. For example, students who provided totally inaccurate, incomplete or irrelevant responses were not reflected in the statistics. What the statistics highlight instead are common occurrences across all the classes, which suggests that such errors were perhaps not class-specific but potentially point to factors that were common either among students (e.g., their language backgrounds, level of content understanding) or across the instruction provided to them despite being taught by different teachers.

Discussion

Among the student errors that were found (Table 2), some appeared to be less related to content understanding than others. In this study, the errors related to the use of *Descriptor* seemed unlikely to be related to a lack of student understanding of the blood vessels. Rather these errors have to do with the students not using language that was appropriate to the context (that is, the use of 'thin lumen' instead of 'narrow lumen') or to the demands of the question (the use of 'high' instead of 'highest'). By contrast, the language choices found in other errors (mainly to do with the use of

Process, *Participant* and *Circumstance*) were more related to students' level of content knowledge and understanding, assuming that the students did not make the error out of carelessness. Given that these errors were more likely to be contingent on the nature of the content, the second group of errors in this sense reflected a lack of discipline-specific literacy, whereas the first group likely involved a lack of general academic proficiency (Fang 2012; Shanahan and Shanahan 2008).

By considering particular language choices as a constituent of discipline-specific literacy, we can infer the discipline-specific language knowledge that would be required of students to make these language choices appropriately. In this study, the erroneous use of *Participant*s dominated the other types of linguistic errors. This is not surprising when one considers a fundamental aspect of learning HCS: recognising and differentiating between the various structures involved in the functioning of HCS as a system. This entails learning a large volume of topic-specific (and often unfamiliar) terms that label the various organs, tissues, and their subparts that together constitute the system as a whole. Moreover, from a functional language perspective, *Participant*s are a critical linguistic resource 'for compacting information, creating technical objects, developing logical reasoning, facilitating discursive flow, and achieving precision and concision', and are thus privileged in scientific language (Fang 2012, p. 25). From a linguistic perspective, the students' errors suggest the challenge involved for them in making an accurate and precise choice of linguistic resources to identify the *Participant*. To make such a choice would entail due consideration on the part of the students in terms of the precision of structure involved in a particular phenomenon.

Identifying reasons for such errors could aid teachers' understanding of student struggles with the topic of the HCS and other terminology rich biology topics. Several reasons might account for erroneous *Participant*s. One of the most obvious was the lack of understanding of how the various structures function, which resulted in confusion between the different structures or functions. The traditional alternative conceptions research would view such errors as a reflection of misconceptions. Another reason commonly cited by teachers from my interviews with them would be retention failure due to the students not being able to recall the relevant structures and/or unfamiliar terms. I would like to propose another equally plausible but less apparent explanation: that the students might not have recognised the need to differentiate the structures to the extent that biologists do, to create what is eventually ‘a complex lexical taxonomy’ (cf. Halliday 2004, p. 151). This was especially relevant when the issue with *Participant*s was the lack of specificity, such as when students failed to differentiate between capillaries and the walls of capillaries (in item BV-Q3b) and when they did not specify which valve closes during ventricular systole (in item HS_Q2b). Such errors also occurred in the use of non-specific *Circumstances* in item Hs_Q3b, where the students merely identified the location of the tricuspid valve as the ‘right side of the heart’, instead of specifying its precise location between the right ventricle and right atrium. The lack of specificity in both the *Participant*s and *Circumstances* suggests that students might not have recognised the *importance* of differentiating between structures or understood the *disciplinary rationale* for doing so.

A very critical component of biology is the study of biological structures and their functions. While an organism can be differentiated into various levels of organismal organisation (cell, tissue, organ, organ system), differentiation within these levels can be just as important depending on the biological function being studied. For example, the role of capillaries and their walls differ. When studying how blood is transported within the tissues, the structure in focus would be the blood vessels. However, knowing the presence of and the function of capillaries in transporting blood would not suffice if one is to understand how substances within the blood are transferred out of the capillaries. This would entail knowing the role and characteristics of the capillary *walls*. In classrooms, teachers may refer to the different parts of the HCS and their respective role. However, they are less likely to emphasise *how* the physical structures are distinguished and related to each other (e.g., how the layers of the walls of a vein may be distinguished); and more importantly, *why* they need to be differentiated (e.g., due to distinguishing features and functions). Hence, students may not appreciate the rationale for such intricate differentiation. Similarly, students may know the general function of valves (that is, closing to prevent backflow of blood) but may be less able to appreciate that different valves (e.g., the semi-lunar valves and the ventricular valves) have different roles to play in the cardiac cycle. This may partially explain why some students may not see the need to identify the specific valve concerned. In other words, even if students know there are different valves, if they do not understand how and why the distinctions matter, they will not attend to the distinctive role of the complex network of components constituting the HCS. Their failure to do so would in turn hamper their understanding of HCS as a system (cf. Raved and Yarden 2014).

Another related error is the problematic use of *Process* in connection with the action of muscles. This is not surprising given that the students had not been taught the mechanism of how muscles function. Hence, they were likely to fill in the knowledge gaps with their own imagination of how muscles actually work. From a linguistic perspective, this could explain the students' varied choice of verbs to describe the actions of muscles, which suggest attempts to substitute with words that are similar or close in meaning to those words used by their teachers. Nonetheless, they had yet to appreciate that these words can have different connotations, and are not considered interchangeable in science as they would be outside the science classroom.

The lack of differentiation with respect to both structures and their actions is linked to the hallmark of precision in scientific language (O'Toole 1996). As each structure plays a distinct role and has distinct features, naming each structure and its role serves a specific need of science in the generation and communication of knowledge, and thus contributes to the precision demanded in scientific language. From a socio-semiotic perspective, the lack of precision in the choice of

Participants and *Processes* suggests that students might not have recognised the difference in expectations for precision between every day and scientific use of language, and the rationale for the difference. This lack of recognition can in turn hamper students' use of language to represent their meaning as they may assume that they are expressing the scientific meaning without recognising the ambiguity in their language. Pelaez et al. (2005) observed that the lack of precision in the use of language on HCS was evident even among prospective elementary teachers.

The need for precision in science (for example, when there is a need to differentiate between previously undifferentiated parts of a biological structure) often necessitates the generation of new science terms by scientists. However, this fundamental scientific practice of creating a set of coherent and comprehensive terminology when generating new knowledge has not been given adequate emphasis in curricular and instructional practice. This is in contrast to the attention given to scientific practices that generate scientific content in the form of propositions and theories as set out in the NGSS. Understanding the language generation process has implications for the learning of science, given its role in establishing the features and conventions of scientific language, which in turn have impacts on how science is represented and understood.

One characteristic of the errors made by the students was their robustness. Like alternative conceptions of the HCS (Pelaez et al. 2005), some student errors appear to persist in spite of their teachers pointing them out. This would not be surprising if the students do not appreciate the level of precision and differentiation demanded in scientific knowledge and language. There are several implications here for science teaching and learning. Firstly, learning HCS goes beyond learning a particular 'model' of how the body works but involves learning a new language (Brown and Ryoo, 2008). In unpacking and explaining the errors in student explanations from the language perspective, this study provides further empirical evidence that affirms what other researchers have argued (e.g., Fang 2005), namely the need to foreground the role of language in science teaching and learning. Secondly, learning the language (particularly vocabulary) involves not only learning the meaning of words. Learning the language also involves understanding the rationale for these precise terms and how they arise from the way biologists have come to understand the circulatory system and describe the working relations of its various components. Not appreciating how this body of terminology came about (or why it emerged) and the role it serves can mean that students do not understand why they must use certain words even when other alternative non-disciplinary terms seem to convey similar meaning.

Instead of viewing student language use as flawed, it is more fruitful to view their use of language as part of their attempts to interpret the knowledge and practices of science. Their language use might mirror scientists' initial tentative and figurative use of language when constructing a new theory or exploring ways of interpreting and explaining natural phenomenon (Sutton 1992). Sutton describes 'language as a labelling system' with specific characteristics: 'definite, precise, needing the right word for the right thing' (Sutton 1992, p. 6). He recommended that teachers 'present the language of scientists as a human product' with a history and explore with students 'the thought behind a particular choice of words' (p. 13). Students' erroneous attempts may thus be due to a lack of alignment in their choice of language with what is favoured by scientists for its precision and clarity rather than indicating a lack of alignment between their understanding and that of scientists. While the latter view has been given much more attention (e.g Chi et al. 1991), the former view is less recognised.

Implications for Teaching and Teacher Learning

This study has highlighted the importance of developing students' awareness of the role language plays in constructing scientific meaning. One strategy is to engage students in exploring multiple ways of expressing a scientific idea and explicitly discussing the extent to which their expressions capture the idea with precision in terms of both word choice and the way the words are put together

(Sutton 1992). Another approach is to engage students in classifying the terms that are essential in the topic and exploring both the differentiation and relations between terms within and between categories. In the course of the classification, teachers can engage students in discussing how these terms relate to the crosscutting concepts (e.g., structure-function) and the practices of biologists (e.g., differentiating structures and modelling their functions). By explicating the form-function relations of scientific language, students can better appreciate the way language is used in science and why the terms need to be used in particular ways, rather than experiencing scientific language as an alienating and arbitrary set of symbols. In the context of the present study, such approaches can raise the level of students' consideration when selecting the accurate and precise *Participant* or *Process* to represent the structure and action at play.

Engaging in such discussions would entail science teachers deepening their language awareness beyond being fluent in the language of science to possessing knowledge about how this language functions (Andrews and Lin 2017), particularly, knowledge about how scientific language relates to scientific practices. For example, teachers would need to know the purpose of the language that has developed around a topic such as the HCS and the function the terminology and the crosscutting concepts play in construing knowledge about how HCS works. Other researchers, such as Bunch (2013), Morton (2016) and Turkan, de Oliviera, Lee and Phelps (2014) have also identified a body of knowledge about language that content teachers could tap into in order to support their students in acquiring the knowledge. Though their research is mainly in the context of English Language Learners (ELLs) and multilingual learners, the knowledge for teaching language and literacy practices unique to a discipline is relevant not just to ELLs but also native English speakers.

Conclusion

This study has demonstrated the value of conducting a fine-grained examination of students' language use in revealing the demands of learning HCS beyond the conceptual demands previously identified in other studies. The aspects of language highlighted as of importance in this study also point to scientific practices that can have significant implications for science teaching and learning. Nonetheless, this study was based on one topic, inevitably raising the question of the extent to which the same findings (e.g., the prevalence of non-specific *Participants*) apply to other biology topics and to other scientific disciplines like chemistry and physics. For example, would it be more likely to find similar findings in topics in which numerous differentiation between entities are required than those in which such differentiation is less crucial? Another question is whether similar kinds of errors occur in other classrooms, educational systems, and cultural contexts. Future studies could unpack the relations between instruction and students' cultural and language backgrounds with the varied ways students use language.

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Table 1. Types and description of students' language errors

Category	**Description: Error due to**	**Instances**
Process error	use of a verb or verbal group, which identifies the action or relationship going on	contract, constrict, can be exchanged
Participant error	use of a noun or nominal group, which identifies the entity participating or involved in the relationship or action	capillary wall, the function of the tricuspid value, it
Descriptor error	use of an adjective or adverb, which describes the nature of either the *Process* or one of the *Participant*s	highest, lower, elastic,
Circumstance error	use of a preposition or prepositional phrase, which elaborates on the *Process* or one of the Participants	to prevent backflow of blood, into the left ventricle to the left atrium
Connective error	use of conjunction or logical connector that indicates the logical-semantic relationship between two ideas or clauses	and, so, therefore
Missing word	the lack of a key word or phrase	level [#1][of] oxygen, more oxygenated [#1][compared] to
Irrelevant word	the presence of an unnecessary word or phrase	go against gravity [#2][and other blood flows in the human body]

[#1]*[words in brackets are missing];* [#2]*[words in brackets are unnecessary]*

Table 2. The question stem, nature and example of the six errors that were found in all classes

Item No.	Question stem	Category of error: Instances	Example of a student response with error
*BV_Q1a	A student describes the arteries in our body as follows. *Arteries usually transport deoxygen blood from the heart to other parts of the body. Arteries have thin wall and thick lumen.* However, three of the words used in the description are incorrect. <u>Underline</u> those words that are incorrect, and rewrite the statements with the correct words in the spaces provided.	**Inappropriate** *Descriptor* error: Elastic/thick/thin (lumen)	Arteries have thick wall and ***thin*** lumen relative to its diameter.
BV_Q1b	Compare the level of blood pressure that can be found in	**Inappropriate** *Descriptor* error: high/low/higher/ lower	An artery have ***high*** blood pressure, an

	an arteriole, an artery and a capillary.		arteriole and capillary have ***low*** blood pressure.
BV_Q1d	Describe what happens to the muscle in the wall, size of the lumen and rate of blood flow when an artery constricts.	**Inappropriate** *Process* error: [muscle] constructs/expands/weakens/increase in size/tightens/become bigger/decrease in size/narrower/wider/thinner/forced to squeeze closer	The muscle in the wall will ***decrease in size***
BV_Q3b	Describe one structural feature that is found in the capillaries but not the veins.	*Participant* error: **non-specific** pronoun such as ‘it’; inaccurate *Participant* (‘capillaries’ instead of ‘capillary walls’)	***Capillaries*** are one cell thick.
HS_Q2b	Describe what happens to the ventricle, the valves and the blood flow in the left side of the heart during ventricular systole. [3]	**Non-specific** *Participant* error: valves	During ventricular systole, the ventricle contracts, the ***valves*** close...
		Inaccurate *Participant* error: mixup of structural	The valves open and the blood

		parts (e.g. ventricle ↔ atrium)	flows from the left ***ventricle*** to the left ***atrium***.
HS_Q3	State the function of the tricuspid valve and its location in the heart.	**Non-specific** *Circumstance* error: 'on/at/in the right side of the heart', 'between the right atrium and left atrium', 'in the right atrium', 'left side of the heart/ventricle', 'between the pulmonary vein and right atrium', 'between both right and left atrium'	The tricuspid valve is located ***at the right side of the heart***.

*For the item code, the letters before the underscore indicate which of the two tests (BV for test on blood vessels and HS for test on heart structure) the item was taken from, whereas those after indicate the item number.

Table 3. Frequency of the errors across the four classes

Item no.	Type of error	Class A	Class B	Class C	Class D	Total	
		[n=20]	[n=14]	[n=16]	[n=20]	[n=70]	
		%	%	%	%	Freq	%
BV_Q1a	Use of inappropriate *Descriptor*	25.0	7.1	60.0	60.0		38.6
BV_Q1b	Use of non-specific *Descriptor*	40.0	35.7	33.3	25.0		32.9
BV_Q1d	Use of Inappropriate *Process*	35.0	21.4	40.0	45.0		35.7
BV_Q3b	Use of inaccurate or non-specific *Participants*	35.0	7.1	46.7	30.0		30.0
HS_Q2b	*Use of non-specific *Participants*	25.0	35.7	25.0	60.0		37.1
HS_Q3	Use of non-specific *Circumstance*	25.0	21.4	13.3	20.0		20.0

*As the two kinds of error in HS_Q2b were of similar type (*Participant* errors), their frequencies were combined in this table.