8 Advancing students' scientific discourse through collaborative pedagogy

Marnel Mouton, Ilse Rootman-le Grange, and Bernhardine Uys

Introduction

Scientists use the scientific method, which involves research questions and hypotheses: probable explanations based on observations. This is followed by meticulous design and execution of experiments and eventually the validation, refinement or rejection of the hypotheses (Carrol and Goodstein 2009). New findings are disseminated through publications where scientists argue the validity of their research among their peers, with the main aim of persuading their colleagues of the validity of their claims (National Research Council 2007). Their discourse presents logical arguments that aim to maximize the probability that readers will acknowledge the findings (Dyasi 2006). In general, scientific language displays objectivity by using abstract nouns derived from verbs and the third person passive voice, as well as numerous technical terms. It is, therefore, semantically dense and impersonal, and like all types of academic discourse, uses 'power words and grammar' to package the knowledge of the field (National Research Council 2007; Marshall and Case 2010; Martin 2013). This specialized language is, however, practically foreign to novices in the field (Marshall and Case 2010; Ambitious Science Teaching 2015).

Gee (2005) conceptualizes scientific language as one type of discourse, which he calls 'little d' discourse – the reading and writing typical of a certain community. This discourse may be very challenging for science students (novices). The second type is described as 'big D' Discourse, which presents the ways and values of a particular group or community, including reading and writing, but also 'behaving, interacting, valuing, thinking, believing and speaking' (Gee 1996; Marshall and Case 2010). Interestingly, the 'little d' discourse echoes the 'big D' Discourse thinking and valuing of the community. In the context of higher education, first-year science students are still newcomers, and Marshall and Case (2010) describe them as 'outsiders' to the language and practices ('little d' discourse and 'big D' Discourse) of the science disciplines. Their lecturers, on the other hand, are usually typically experienced scientists and therefore 'insiders' to the specific discipline, with its unique practices and academic d/Discourse (Marshall and Case 2010). Their role should thus be to induct their

DOI: 10.4324/9781003055549-11

students to become participants in the d/Discourse of the scientific community by promoting participation.

Higher education science classrooms are often more lecture orientated. Such practice may prevent participation, through argumentation, or even regular conversations about scientific topics. As 'insiders,' lecturers often regard the different ways to communicate the ideas in science (e.g. graphs, tables, representations) as self-evident, while the meanings of these may not be obvious to students because it is not made explicit in lectures and assessments. Marshall and Case (2010) therefore reason that 'in not allowing space for a critical engagement with these values and ways of thinking, numerous students are implicitly excluded from successful engagement with the subject.' Furthermore, in considering international practice, Case and co-workers (2013) argue for the importance of 'making explicit the academic literacy practices (d/Discourse) of the discipline' to advance learning for all students (here, academic literacy refers to the development of academic language skills and thinking strategies that are essential for successful study in the various disciplines). To achieve a more desirable outcome, therefore, educators need to make an effort to model scientific d/Discourse, and offer students opportunities to practice this specialized language. This includes actions such as scientific argumentation, using evidence to support knowledge claims, hypothesizing about scientific phenomena, writing up experiments and referring to data and patterns in data. When educators involve students in scientific writing, for example, the students engage in a metacognitive activity where they not only contemplate the correct wording to communicate their thinking but also reflect and clarify their thoughts in the process (Institute for Inquiry 2015). Such practice allows them to develop their discourse (scientific language) while fostering their scientific reasoning.

Various studies have looked at ways in which students' scientific argumentation and language can be developed. Engle and Conant (2002) proposed 'productive disciplinary engagement,' where connections are made between students' learning activities and the ways of scientific discourse (National Research Council 2007). Lee and Fradd (2002) argue for 'instructional congruence' where educators use students' language and cultural experiences to make science relatable, accessible and also meaningful (National Research Council 2007). This can be facilitated by providing students with opportunities to contemplate on and grasp new ways of thinking, with a balance between being challenged, yet feeling safe to experiment (ensuring that their norms and practices are valued). Other studies showed that the use of scientific language depends on students' everyday language established in their past or established over time (McNeill *et al.* 2005). Also, when science students must purposefully use language functions to articulate science, their content knowledge, as well as their language and mathematical proficiency, have been shown to improve (Dyasi 2006). This is due to its role as a key cognitive tool in the development of problem-solving and higher-order thinking. Kelly-Laubscher and co-workers (2014, 2017) highlighted the importance of exposing students to examples of the level of scientific writing they are expected to produce and assisting them in deconstructing these texts to better understand what is expected of them. Thus, educators need to draw on the present strengths of students, raise their awareness of the various types of discourse and make connections between them, and also make explicit what is expected from them. This way, science students will learn the 'rules of the game' and that scientific discourse is distinct for the purpose of building theories, interpreting data and logically communicating new findings. And also, that explanations and claims in science always need to be supported by rigorous scientific evidence (McNeill *et al.* 2005).

Scientific writing is demanding for the majority of students, including English-speaking students writing in their home language (McNeill *et al.* 2005). Chimbganda (2000) showed the various strategies that first-year Biology students, with English as a second language, use to compensate for their limited writing proficiency. And Clarke (2015) reported on the influence of first-year students' prior writing experiences at the school level on their word and grammar choices. Moreover, it was found that students require more skills to communicate their scientific thinking in written form than in verbal form due to a higher level of language skill needed for writing than for speaking (McNeill *et al.* 2005; Institute for Inquiry 2015). This implies that students' language proficiency will have an impact on the development of their scientific discourse. In South African schools, the language of instruction (mostly English), is often different to the learners' spoken home language, which further impacts the development of their scientific discourse. According to Boughey (2002), problems arise because students struggle to 'manipulate the forms of the [language of instruction] in a way that would allow them to receive and pass on the thoughts developed in the disciplines.' Some authors consequently argue for a pedagogy that will recognize that students oftentimes may not have the necessary language skills required to succeed in some disciplines, such as the sciences (Hurst 2010; Kirby 2010). Moreover, Maton (2013) showed that there is often a disconnection between complex disciplinary reading or 'high-stakes reading,' and the production of appropriate discourse or 'high-stakes writing.' To address some of these issues, many institutions of higher education have implemented independent (add-on) academic literacy courses and modules (Boughey 2002; Jacobs 2007). However, a host of studies have shown that academic literacy is taught more effectively when combined with disciplinary content or 'literacy across the curriculum,' compared to the non-integrated approaches (Boughey 2002; Jacobs 2007; Case *et al.* 2013). Jacobs (2007) argues that disciplinary discourse should be made explicit to students by their lecturers, while simultaneously introducing them to the forms of inquiry and knowledge production of the specific discipline. Kirk (2019) corroborates this by stating that academic literacies curricula are not neutral for the communication of academic knowledge and that language studies should not be presented separately from discipline content to advance learning for all students.

In this study, we focus on first-year Biology students' scientific discourse skills, and we explore ways to develop this fundamental skill. Here, discourse refers mostly to 'little d' discourse but also implicitly to 'big D' Discourse. Key goals were to help students' bridge the gap between reading complex discipline content and writing scientifically ('little d' discourse), and equally important, to make the ways of inquiry and knowledge production in Biology explicit to the students ('big D' Discourse). To develop students' discourse skills, we followed the scholarly approach of 'collaborative pedagogy' (Jacobs 2007) by cooperating with our colleagues, the academic literacy lecturers. The idea was for these lecturers to help our students gain mastery over textual choices for, in this case, Biology knowledge practices. Together, we designed a collaborative project to provide the first-year Biology students with an opportunity to develop their scientific language skills, through an introduction to the forms of inquiry and knowledge production of the specific discipline of Biology. Thereafter, we evaluated their use of scientific discourse from the following summative assessment. Also, we investigated the level of scientific discourse found in their prescribed first-year Biology textbook compared to the level of discourse found in the current high school textbook.

Theoretical framework: Semantics dimension of Legitimation Code Theory

To formulate and design the project as well as analyze the data, we drew on the Legitimation Code Theory (LCT) concept of *semantic density*, which explores the degree of complexity of meaning (Maton 2013, 2014a, 2014b). LCT is a realist framework that considers knowledge practices. It is a multidimensional toolkit that offers different dimensions to analyze particular sets of organizing principles which underlie practices. LCT conceptualizes the complexity of meaning as *semantic density*, which can be weaker or stronger along a continuum and can also be weakened and strengthened in practice.

Scientific language is generally complex and therefore represents stronger semantic density. However, complexity is a relative term, and often simply refers to the cognitive demand of the assignment. In contrast, semantic density affords greater specificity, conceptualizing complexity in terms of the condensation of meaning within practices, where condensation refers to adding meaning to a term or practice. In this chapter, we worked with *epistemic–semantic density* (ESD), which deals with epistemological condensation of formal disciplinary definitions and descriptions (Maton and Doran 2017). Epistemic–semantic density further explores the relationality of meanings. Thus, the greater the number of relations to other meanings of terms or concepts, referred to as a *constellation* of meanings, the stronger the epistemic–semantic density (Maton 2013; Maton and Doran 2017).

Several studies have investigated teaching and learning in Biology using Semantics. Kelly-Laubscher and Luckett (2016) showed clear differences in curriculum structure between high school and university Biology. Others showed how this gap can be managed by using LCT tools to plan and execute various interventions (Mouton and Archer 2018; Mouton 2019). Other studies have shown that shifts between more complex and simpler meanings (stronger and weaker epistemic–semantic density) are crucial to support cumulative knowledge-building (Maton 2013, 2014a, 2014b). Martin (2013) further showed that complex language choices are associated with these semantic shifts.

In practice, we expect students to express their subject knowledge using discourse ('little d' discourse). However, they often struggle to formulate their responses scientifically, using both simpler and complex meanings. Therefore, the rationale of this chapter is to explore ways of teaching students the 'rules of the game' in scientific writing, using the concept of semantic density, before their summative assessments in which appropriate scientific discourse is expected. In classroom activities, we often use terms such as 'power language' to communicate to students how to formulate scientific discourse. Thus, this study aimed to help students build their Biology knowledge and power language by participating in classroom activities that would facilitate the use of strengthening and weakening semantic density. This approach may assist students to connect the two types of language, mundane and scientific talk, through formulation practice and recontextualization (Skovholt 2016).

Methodology

In this chapter, we explored ways to develop the scientific discourse of first-year Biology students, for both their reading and writing, and thereafter we studied their use of this fundamental skill in a summative assessment. The Biology lecturer, therefore, identified a section in the first-year curriculum where students have struggled with articulating their conceptual understanding using appropriate scientific discourse, especially during written assessments. To develop the students' scientific writing skills, a project was designed using collaborative pedagogy, thus cooperation between the disciplinary lecturer (Biology) and the academic literacies lecturers, who also teach the same group of students' general scientific communication skills in a separate module. During the project, students worked in groups of three, researching specific structures found in eukaryotic cells. To practice scientific writing, they had to compile a written report about the structure and function of the organelles and systems found in these cells. The next step was to submit the report to the academic literacies' lecturers for feedback on the language and grammar of their writing. After revising their reports, they then submitted the final version to the Biology lecturer who assessed the scientific content, argumentation and discourse.

To analyze individual students' use of scientific discourse after the developmental opportunity, the final written assessment of the semester was used. Six students were selected, representative of the cohort, considering their achievements, their Biology background, as well as their language proficiency. The summative assessment covered most of the semester's content and also included the content of the project and written report. The discourse that we analyzed for this chapter focused on the nucleus and nuclear envelope, a section of the prescribed first-year Biology curriculum. To further contextualize our study, we also analyzed the corresponding content from the school and first-year Biology textbooks.

Participants

Students enrolled in the Extended Degree Programme (EDP) Biology module (Biology 146; instructed in English) at a South African University, participated in the project. The EDP had been implemented for students from previously disadvantaged backgrounds who fall just short of the university's programme entry requirements for mainstream offerings. The summative assessments of six students, representing various levels of academic proficiency were selected for the semantic analysis. An aspect that has to be taken into account is the fact that not all of the students in this group took Biology as a school subject. Moreover, a significant number of these students received secondary education in languages other than English. English, which is the language of instruction in this module, was often their second language.

Developing a translation device for semantic density analysis

Maton and Doran (2017) proposed a 'generic translation device' for analyzing how epistemic–semantic density (ESD) realizes in English discourse. They offer different tools for individual words, word-grouping, clausing and sequencing. Here we have related the translation device for wording to scientific discourse as Figure 8.1. This device can be used to analyze the complexity of meaning expressed by words in the discourse and how meaning is added or increased through combining words with additional words. For this study, we used both the wording and word-grouping tools (Biology examples have been included in Table 8.1).

Wording tool

The wording tool is divided into two broad categories or types – namely, *technical* words and *everyday* words. The meanings of technical words are often 'assumed within their specialized domain unless located in pedagogic settings' where their technical character may have to be emphasized. Moreover, technical words carry significance to specialists in the field, whereas they may appear foreign or dense to non-specialist readers. They are often nouns, longer words, names or place names with clearly defined meanings and strictly defined relations to specific contexts (Maton and Doran 2017). As a result, technical words are placed at the more complex, stronger end of the epistemic–semantic density continuum (ESD+).

Table 8.1 Epistemic–semantic density categories of Maton and Doran (2017) with descriptions and examples from students' discourse

	ESD category	*Sub-subtype category*	*Description and examples from student discourse*
ESD+ ↑	Technical; Conglomerate; Properties	8	This group typically includes actions and processes with multiple distinct parts each with its technical meaning. E.g. 'assisted exchange' and 'protein synthesis.'
	Technical; Conglomerate; Elements	7	This group also contains concepts with multiple distinct parts but does not include processes or actions. E.g. 'nuclear envelope' and 'eukaryotic chromosome.'
	Technical; Compact; Properties	6	This group typically includes actions and processes but with a single meaning. E.g. 'shuttling' (cargo) and 'expression' (gene).
	Technical; Compact; Elements	5	This group includes concepts with a single technical meaning. E.g. 'nucleus' and 'membrane.'
	Everyday; Consolidated; Specialist	4	This group contains concepts that are used in everyday language but in this context is dominated by specific technical meaning. E.g. 'hereditary information' and 'genetic material.'
	Everyday; Consolidated; Generalist	3	This group contains concepts that are used in everyday language but in this case has a more general technical meaning. E.g. 'signal' (noun) and 'molecule.'
	Everyday; Common; Nuanced	2	This group includes concepts that are used in everyday language and represent single happenings or qualities. E.g. 'reinforced' and 'embedded.'
↓ ESD–	Everyday; Common; Plain	1	This group contains concepts that are used in everyday language with relatively general meaning. E.g. 'separate' and 'line.'

On the other end, *everyday* words represent simpler meanings and therefore weaker epistemic–semantic density (ESD–). The meaning of everyday words is not set in specialized fields and they are generally judged based on their usage in more common contexts. They are often shorter words in comparison to technical words and can be any word type (nouns, verbs,

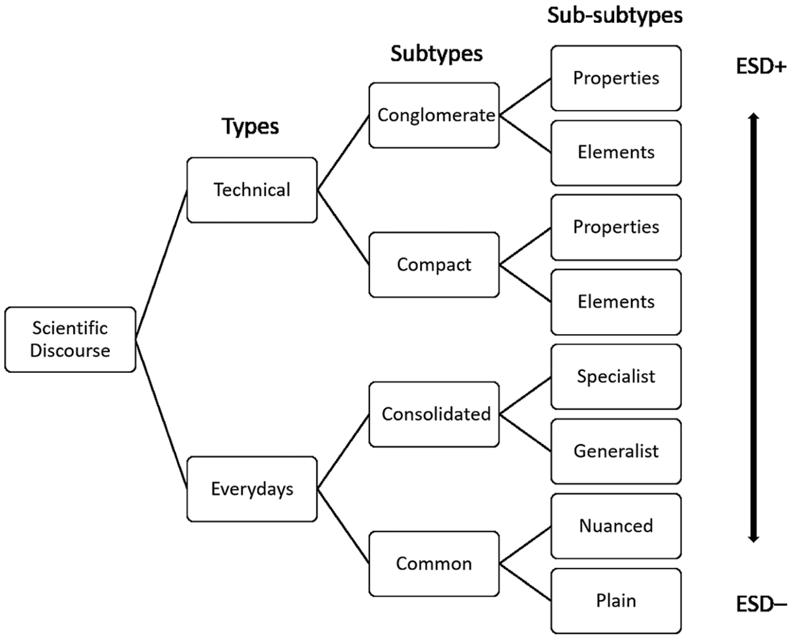

Figure 8.1 Wording tool for epistemic–semantic density in English discourse (Maton and Doran 2017).

adjectives, etc.). Everyday words can be related to a wide range of words without losing meaning, creating more fluid relations to various contexts.

At the next level of the wording tool, the two types are further subdivided to create four subtypes, which are then further subdivided to end up with eight sub-sub-types, as shown in Figure 8.1.

Subtypes of technical words

Technical words comprise *conglomerate* words and *compact* words. Conglomerates, as the term suggests, are words containing more than one part or concept, each one having a technical meaning. In contrast, compacts are single units with a single technical meaning. Conglomerates are therefore considered to be more complex (have stronger ESD) compared to compacts, as they contain more meaningful parts. The sub-sub types of both conglomerates and compacts provide an even finer level of ESD analysis. Elements refer to 'an item, entity or thing of some kind,' whereas properties refer to 'an action or quality of an item, entity or thing.' Conglomerate properties are therefore seen to be more complex (stronger ESD) than conglomerate elements.

Subtypes of everyday words

The sub-categories for everyday words are *consolidated* words and *common* words. Consolidateds encode 'happenings or qualities as things' (e.g. invade and invasion) while commons remain as they are, 'happenings' or 'qualities.' The term 'happening' refers to processes or events normally presented by verbs. Similarly, 'things' refer to items or elements represented by nouns. The finer level introduced for consolidateds distinguishes between *specialist* words and *generalist* words. Specialist words are *consolidateds* set in text dominated by technical words. In contrast, generalist words are *consolidateds* found in text dominated by everyday words. Two subtypes of common words can also be distinguished: *nuanced* and *plain* words. The former refers to words that exhibit more differentiated meanings whereas the latter are relatively general and simpler in meaning, e.g. 'embedded' (nuanced) vs 'lying in' (plain).

Proxy words

These are stand-in or replacement words used in text, such as 'nucleus' and 'it,' where 'it' refers to the nucleus in this case, or the term that was used earlier in the text. In terms of complexity (ESD), proxies are not as strong as the original word but not much weaker either. This is due to proxies not exhibiting the same perception of complexity, even though they represent the original word.

Word-grouping tool

Where the wording tool of Maton and Doran (2017) allows one to rate individual words in terms of epistemic–semantic density, the *word-grouping* tool considers the effect of combining or grouping words on ESD (Table 8.2). When words are grouped, they can often strengthen ESD. Maton and Doran's (2017) word-grouping tool describes three types of word groupings, called modifications, that increase the strength of a word's ESD:

Table 8.2 An adjusted version of the word-grouping tool for epistemic–semantic density (Maton and Doran 2017)

Type	*ESD as proposed by Maton and Doran (2017)*	*How it was used in this chapter; our translation device*
located	ESD↑	ESD↑
categorized	ESD↑↑	ESD↑
embedded	ESD↑↑↑	ESD↑
defined	not included	ESD↑

- *Located* modifications (ESD↑) increase meaning by specifying a specific location in time or space, e.g. 'structures form around the genes.' This allows for further differentiation.
- *Categorized* modifications (ESD↑↑) increase meaning by specifying a distinct type of word, e.g. 'Free-floating nucleotides,' 'unwound DNA.' This allows for further differentiation by indicating the specific type and subtype.
- *Embedded* modifications (ESD↑↑↑) increase meaning by showing that the word is active in an event or process, e.g. 'genes that are responsible for storing the hereditary information.' Thus, this type of modification specifies a specific type of secretion plus a specific type of activity.

Modifications can also be combined. The more modifications that are added in the text for a specific word, the stronger the ESD.

Results and discussion

Biology, like all other academic discourse, uses 'power words and power grammar' to elucidate the knowledge of the field. Martin (2013) describes 'power words' as technical terms with a 'greater strength of semantic density' and 'power grammar' as the 'knowledge construing power of grammatical metaphor' (which is one way of strengthening ESD). Thus, a discipline's knowledge gets packaged into text that stores the descriptions of the knowledge field. Each discipline is characterized by a unique genre, and students need to master the unique power composition of each discipline to know how to scaffold and organize these genres for the particular discourse, especially in written assessments. According to Martin (2013), power composition incorporates both power words and power grammar to organize writing that regularly shifts between complex meaning (ESD+) and simpler meaning (ESD–). This leads to academic writing that is precise, critical and objective, composed of complex meaning that is based on concrete evidence.

The textbooks

We examined the discourse of the two textbooks familiar to our students: the prescribed first-year textbook used in this module and the prescribed school textbook from their previous learning. Students must be able to access the knowledge in these sources by reading, and these textbooks would also serve as models for students to scaffold and organize the genres for their Biology discourse. We reasoned that understanding the discourse profiles of these texts in terms of power composition would serve as a baseline for comparing the students' discourse. Our analyses showed that the scientific discourse used in these two textbooks differed significantly with regard to complexity, density and volume (Figure 8.2). In Figure 8.2, complexity of meaning is weakest at the bottom of each bar and becomes stronger towards the top (Sub-subtype categories 1 to 8). Thus, the bottom band is weakest and the band second from the top representing the most complex meaning. The

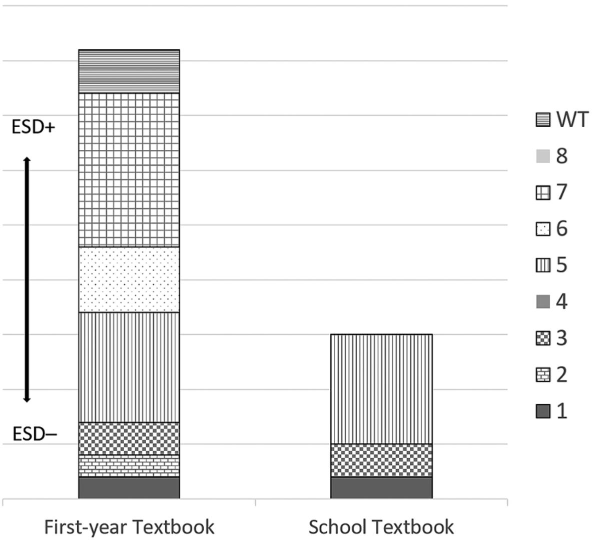

Figure 8.2 Bar graph indicating proportion of simpler to more complex meaning in the respective descriptions of the nucleus of a eukaryotic cell from the first-year and the school textbooks.

band on the top of each bar represents terms that strengthened the complexity of the descriptions (word-grouping tool). Although a difference between these two resources seems obvious and was therefore anticipated, we completely underestimated the magnitude of the variance, both quantitative and qualitatively. Firstly, the volume of text in the first-year textbook is significantly greater than that of the school textbook. Moreover, the first-year textbook uses a wide range of words and terms, with many coming from the two high-end, more complex meaning categories 6 and 7 (Technical; Conglomerate; Elements and Technical; Compact; Properties). Terms from these two categories (6 and 7) are completely absent from the school textbook. Thus, the first-year textbook uses far more words (quantitative) and significantly more power words and compositions (stronger ESD; qualitatively) than the school textbook, which is very elementary in comparison. Moreover, there is significant epistemological condensation from the school to the first-year textbook and curricula. *Condensation* refers to the process of adding meaning, in this case to biological terms (Maton and Doran 2017), where substantial meaning is added to terms they have learnt in school. Thus, when first-year students engage with their new curriculum and textbook, they are suddenly confronted with an exceptionally steep increase in volume, as well as complexity and density in meaning, which includes an increase in the number of power words and added meaning to known terms. Many newcomers are underprepared for this steep learning curve. Valencia (2014) found a similar situation with high school learners struggling with textbook reading and argues that these texts are 'not structured like any other authentic reading.' The students who read these textbooks already have to deal with learning many new concepts and data. Moreover, they are also confronted with new ways of thinking and reasoning that are important to the subject matter. Many of the students have not developed the necessary comprehension skills for learning from such text. Valencia (2014) therefore argues that 'not only do [the students] need to learn the content, they also need to learn how to learn from complex subject-matter texts.' Our study revealed a similar situation in this first-year cohort.

Students' scientific vocabulary

We found that the scientific vocabulary and use of power words varied considerably among the students in the summative assessment. Figure 8.3 shows that three of the six students (Students 4 to 6) displayed a proficient command of the Biology vocabulary (power words with stronger ESD) and grammar needed to describe the structure and functions of the nucleus of the eukaryotic cell. The remaining three students (Students 1 to 3) struggled to effectively portray this biological structure and all its components using written discourse. In Figure 8.3, complexity of meaning is weakest at the bottom of each bar and becomes stronger towards the top (Sub-subtype categories 1 to 8). Thus, the bottom band is weakest and the band second from the top representing the most complex meaning. The band on the top of each bar represents terms that strengthened the complexity of the descriptions (word-grouping tool). When comparing the students' descriptive accounts to the first-year textbook, it was encouraging to see that Student 4 managed to use most of the terms from the textbook, and further demonstrated a sound understanding of how these components fit together and relate to one another (power composition), as shown by the concept map in Figure 8.4a (a tick

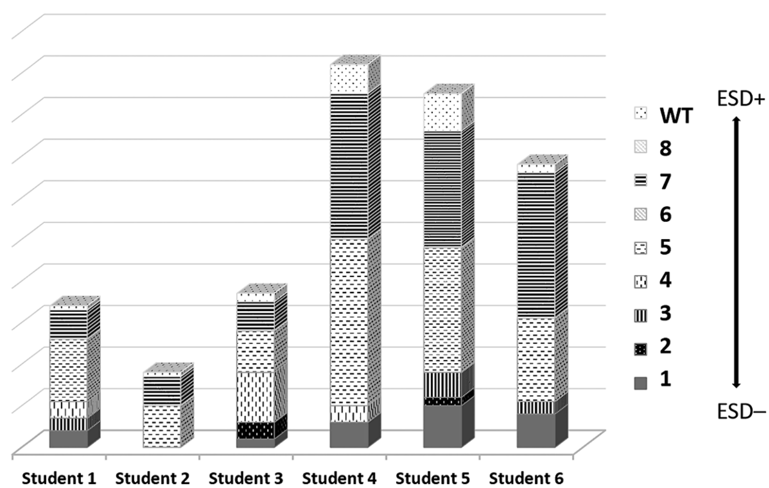

Figure 8.3 Bar graph indicating proportion of simpler to more complex meaning in the respective descriptions of the nucleus of a eukaryotic cell from the students' (1 to 6) final summative assessments.

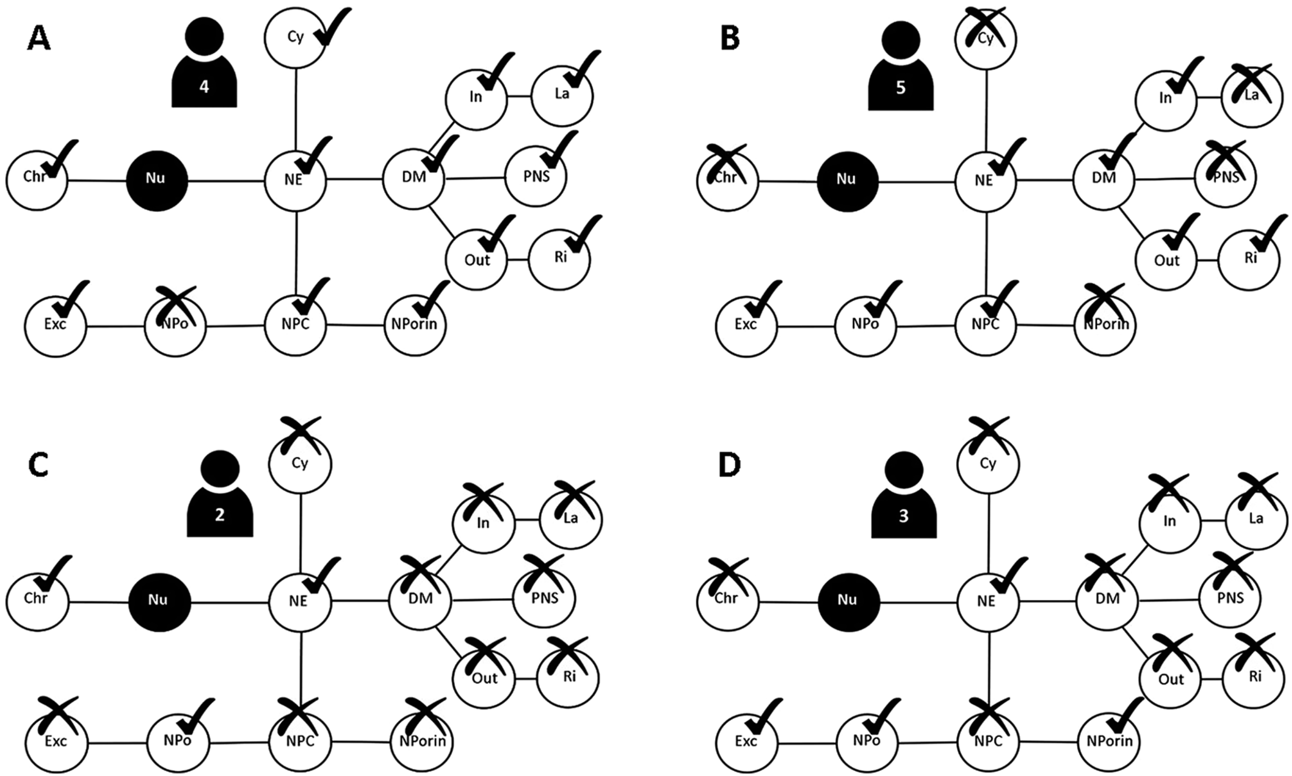

Figure 8.4 A–D Concept maps of students' biology vocabulary describing the nucleus of a eukaryotic cell.

mark represents a concept being used and an 'X' indicates that the student omitted the specific term. Nu = Nucleus; NE = Nuclear Envelope; Cy = Cytoplasm; DM = Double Membrane; In = Inner Membrane; Out = Outer Membrane; La = Lamin; Ri = Ribosome; PNS = Perinuclear Space; NPC = Nuclear Pore Complex; NPo = Nuclear Pore; NPorin = Nuclear Porins; Exc = Exchange; Chr = Chromatin/Chromosome). Student 5 applied fewer of the relevant terms to depict this cellular structure (Figure 8.4b), although his understanding and expression of the relations between the concepts was skilful and sound. In contrast, Students 1, 2 and 3 used a limited number of terms (some of which appeared in the question) and demonstrated significantly less comprehension of the concepts, despite the earlier developmental opportunity. Their understanding of how the concepts and components fit together and relate to each other, using power grammar, was also impeded (Figures 8.4c–d). These three students struggled to access the complex discipline-specific knowledge, or as Boughey (2002) argues, had problems with 'manipulating the forms of the additional language in a way that would allow them to receive and pass on the thoughts developed in the disciplines.' Valencia (2014) reasons that many students struggle to use their textbooks because 'the chapters are long and packed with specialized vocabulary; assumed background knowledge that students often don't have.' In contrast to Students 1 to 3, Student 6 was able to use many of the more complex terms (power words) as shown in Figure 8.5. Interestingly, this student is English-speaking (home language) but did not take Biology at school. So, although we witnessed her working hard to obtain the necessary power words (Biology vocabulary), her insight into how these concepts fit together

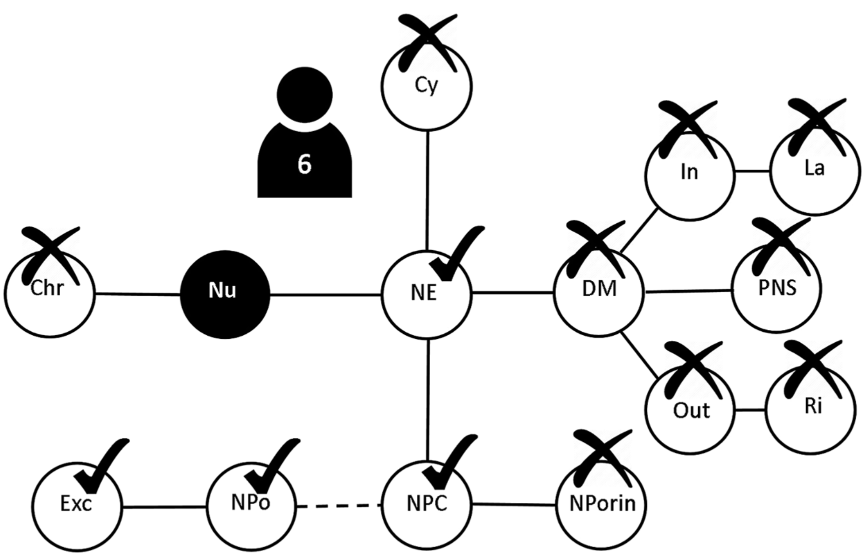

Figure 8.5 Concept map of Student 6's biology vocabulary describing the nucleus of a eukaryotic cell.

and relate to one another, needed more time for development (Figure 8.5), which restricted her ability to exhibit power composition. The aspect of discipline-specific scientific vocabulary, therefore, affects conceptual understanding, as well as the ability to communicate that understanding using proficient scientific discourse and power grammar. When students face science assignments or assessments, they need words, ranging in complexity, to firstly think about and process questions, ideas, possibilities and possible answers. Thereafter, they need a discipline-specific vocabulary (power words) to communicate their answers and ideas, either through verbal or written discourse. Dyasi (2006) therefore contends that 'words represent intelligence; acquiring the precise vocabulary and the associated meanings are key to successful scientific thinking and communication.' Our observations and analyses corroborate these arguments, which seems to be particularly true for students who were not instructed in English at school. It, therefore, appears that students who were instructed in English at school, despite having a different home language, have an advantage when it comes to navigating the gap between the school and first-year curricula and textbooks. These students have developed more skills to manipulate the forms of their additional language to express themselves and share their knowledge.

'Unpacking' of complex concepts

Another interesting finding was that the discourse of the students varied considerably with regards to the degree of explaining or 'unpacking' of complex concepts. In Figures 8.2 and 8.3, the complexity of meaning is represented by the respective segments of the stacked bars with the more complex meaning towards the top of the bars and simpler meaning towards the bottom of the bars. When one considers sections 6 and 7 on these stacked bars, these segments represent terms with relatively stronger complexity of meaning, which should be mastered by the students in this curriculum. Our results showed that the students were all able to use terms from both these desired categories. However, some students (Students 4, 5 and 6) excelled in using these terms with greater complexity appropriately. Students 4 and 5 further demonstrated a deep understanding of how these concepts relate to one another. An example from Student 4's discourse demonstrates that this student was able to use her Biology vocabulary (power words and grammar) to write a detailed description of the nuclear envelope of a eukaryotic cell:

> The membrane surrounding the nucleus is called the nuclear envelope. The nuclear envelope has two membranes. It has an inner membrane and an outer membrane and it contains an inner membrane space between the two membranes. The nuclear envelope also separates the nucleus from the cytoplasm and serves as a type of protection as it contains the delicate genetic information.
>
> (Student 4)

This student displayed excellent understanding and mastery of both the knowledge and scientific vocabulary using power words and grammar to describe this cell structure from various perspectives, and we regard this as an example of power composition. Even though she repeats herself to some extent, her detailed description would allow even a novice in the field to form a mental image of this structure. In contrast, despite Students 1, 2 and 3's discourse including some terms from these two high-end categories, they displayed significantly less understanding in their descriptions. For example:

> …that will pass through the nuclear envelope (a membrane that covers the nucleus and allows for specific substances passage…).
>
> (Student 1)

> It [the nucleus] has a membrane called the nuclear envelope that encloses the nucleus' substances and structures as well as allows substances to pass through.
>
> (Student 3)

It was also thought-provoking to notice how the students' descriptions of certain structures differed from the same descriptions in the school and first-year Biology textbooks. Even the less proficient students showed some development in their knowledge when compared to the school textbook, which described the nuclear envelope by saying:

> The nucleus is surrounded by a double nuclear membrane with pores. The pores form the passage between the nucleus and cytoplasm of the cell.
>
> (School Textbook)

Despite the school textbook being moderately dense in meaning, it is relatively low in volume and not very complex. The section we analyzed did not contain any words from the stronger categories, 6 and 7 (Technical; Compact; Properties and Technical; Conglomerate; Elements). We calculated that the text comprised approximately the same number of words from category 5 (Technical; Compact; Elements) as the first-year textbook, however, the text never reached the strongest levels of complexity in meaning in its descriptions of these concepts.

In contrast, the first-year textbook presented both complex and very dense meaning (ESD+). Moreover, there is significant epistemological condensation from the school to the first-year textbook. Condensation refers to the process of adding meaning, in this case to biological terms. Moreover, the descriptions of these terms in the first-year textbook were very concise, compared to the discourse of the proficient students. The students used complex words from both these desired categories (6 and 7), and some students (Students 4, 5 and 6) excelled in using words with strong complexity. The difference between the discourse of these three students and the first-year textbook can be ascribed to the extent of explaining and 'unpacking' done by them when describing the relevant structures. Student 4 used a similar number of complex words as the first-year textbook. However, she repeatedly used specific terms (e.g. 'nuclear envelope'), each time linking the term to a different aspect, information or point of view, revealing different perspectives. In contrast, the first-year Biology textbook uses such a term only once in its description of the same concept. Thus, the way Student 4 elaborated on and constructed the text made her discourse less dense and compact, and therefore more accessible, especially to novices, as she was 'unpacking' the condensed meaning gradually and systematically, shifting regularly between complex and simpler meaning. Referring back to the wording tool and our fourth category (Table 8.2), it is evident that this student often used phrases such as 'called the' and 'just like the,' which makes her written descriptions less compact, and in our opinion more accessible to novice readers. We, therefore, argue that Student 4 models the role of the lecturer in the teaching and learning process by 'unpacking' and 'repacking' the concepts in much detail, using a fair amount of repetition and pointing out various perspectives of the same concept (Figure 8.6; ★ = 'nuclear envelope'). This discourse is a perfect example of Maton's (2013) *semantic waves* where regular shifts can be seen between more complex and simpler meanings. Figure 8.6 shows how the discourse in the first-year textbook compares to that of Student 4 for the description of a specific cellular structure. Despite the textbook description displaying semantic waves, it is much more dense and compact. We, therefore, argue that the first-year textbook is semantically very dense, thereby failing to facilitate epistemological access for many students to this powerful knowledge. Lecturers, therefore, need to make an explicit effort to make this written discourse more accessible to students by 'unpacking' the complex meaning of concepts gradually and systematically (Mouton and Archer 2018) in the way Student 4 modelled.

Throughout our analysis, using the word-grouping tool, we found that proficient students often repeated themselves and frequently used phrases

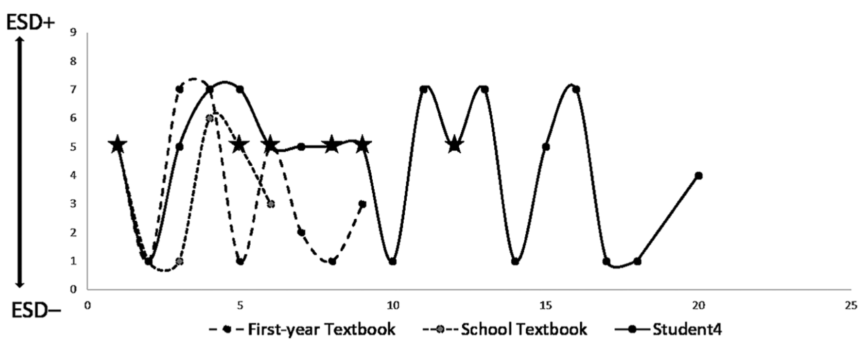

Figure 8.6 Semantic density profile of concept 1 component 2 from first-year and school textbooks, and from final summative assessment of student 4.

such as 'called the' and 'just like the,' that helps to 'unpack' meaning but also enacts accessibility to novice readers. For this study, we, therefore, used an adjusted version of the word-grouping tool with a fourth modification for our analysis that we named 'Defining/Relating' (Table 8.2). This is not the type of phrasing that is typically found in more formal texts such as textbooks. However, in the students' written text, these modifications tended to make the text less dense by being more specific (defining), or by relating preceding words to other concepts. Examples of such modifications would be 'membrane called the nuclear envelope,' or 'just like the plasma membrane, the nuclear envelope prevents…'

Going forward

After reflecting on the results of this study, as well as studying literature showing that 'science talk' is cognitively less demanding than 'science writing' (Institute for Inquiry 2015), the project part of this study was amended for future cycles in three ways: Firstly, within their groups, the students will be given time to work through a given portion of the first-year textbook, discuss the content and make a list of the Biology vocabulary (power words) found in the text. Secondly, they will have to construct a concept map of the given cellular structure to include the Biology vocabulary. The concept maps are meant to promote the processing and synthesis of concept knowledge and to reduce the cognitive load, but also help students discover how each term relates to others in the bigger constellation of meaning. The concept maps will then be used as a basis for the structuring of the written discourse for the project. Thus, students will have time and opportunity to first 'unpack' the complex, dense meaning verbally and collaboratively, and thereafter in a visual concrete manner by constructing a concept map, before having to formulate 'high-stakes' scientific writing. Lastly, an online Biology dictionary has been compiled to help students understand and 'unpack' complex and compact terms by being able to quickly check the meaning of a term before using it in their discourse. In future studies, we plan to investigate the impact of these interventions.

Conclusion

This collaborative project was intended to make the literacy practices and 'genre' of Biology explicit to the first-year students through collaborative reading and writing activities (Jacobs 2007; Kirk 2019). Another objective was to provide students with an opportunity to engage in 'high-stakes reading' by using their Biology textbook and other literature, develop their Biology vocabulary and knowledge, followed by engaging in scientific writing by compiling a report, thus producing 'high-stakes writing.' The project was followed by a summative assessment, which presented another opportunity to showcase their mastery of the content, but also provided material for analyses of their writing skills. We believe that these activities brought some aspects to light: Firstly, the startling and underestimated difference between the school and first-year Biology textbooks in terms of volume, complexity and condensation of meaning, which would explain why so many students struggle to use the first-year textbook effectively. The gap between these two resources is substantial, and lecturers need to be made aware of this to assist students with this transition. Secondly, the variation in the proficiency and command of the students in terms of scientific vocabulary is noteworthy. Some students manage to gain and use a substantial volume of new scientific vocabulary (power words and grammar), while many others struggle to master the much higher volumes and accompanying complex meaning. These students need more time and opportunities to engage in using scientific discourse. Lecturers need to be aware of the wide variation in skills between students and attempt to support them by developing and sharpening these skills. Finally, the variation in skills among the students to manipulate the forms of their additional language in a way that would allow them to receive and pass on the knowledge they have developed in Biology, needs to be acknowledged. This study revealed how proficient students skilfully elucidate complex meaning by gradually 'unpacking and repacking' compact meaning from the textbook. We believe that this is also the role of the lecturer, to unpack and repack the complex, compact meaning for all students.

We believe that learning activities such as the one featured in this study, as well as the ones that will be included in future cycles as a result of these findings (e.g. the construction of concept maps), implicitly 'include' students to successfully engage with the discipline of Biology, and its values and ways of thinking. It contributes to the development of vital skills such as students' scientific discourse but also their identities as future scientists.

Acknowledgements

A sincere thank you to our academic literacies colleague's Mrs Y. Coetsee, Dr A. Binneman, Mrs E. George, Mrs E. Basson, Dr C. Fourie and Mrs F. Haroun for their valuable contributions to this project.

References

Ambitious Science Teaching. (2015) 'A discourse primer for science teachers.' http://ambitiousscienceteaching.org/wp-content/uploads/2014/09/Discourse-Primer.pdf

Boughey, C. (2002) ''Naming' students' problems: An analysis of language-related discourses at a South African university,' *Teaching in Higher Education*, 7(3): 295–307.

Carrol, S., & Goodstein, D. (2009) 'Defining the scientific method,' *Nature Methods*, 6(4): 237.

Case, J., Marshall, D. and Grayson, D. (2013) 'Mind the gap: Science and engineering education at the secondary-tertiary interface,' *South African Journal of Science*, 109 (7/8): 1–5.

Chimbganda, A.B. (2000) 'Communication strategies used in the writing of answers in biology by ESL first year science students of the University of Botswana,' *English for Specific Purposes*, 19(4): 305–329.

Clarke, J. (2015) 'The value of understanding students' prior writing experience in teaching undergraduate science writing,' *Critical Studies in Teaching and Learning*, 3(1): 21–43.

Dyasi, H. M. (2006) 'Visions of inquiry: Science,' in R. Douglas, K. Worth, and W. Binder (eds) *Linking Science and Literacy in the K–8 Classroom*, NSTA Press.

Engle, R.A. and Conant, F.R. (2002) 'Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom,' *Cognition and Instruction*, 20(4): 399–483.

Gee, J.P. (1996) *Social linguistics and literacies: Ideology in discourses*, Taylor and Francis.

Gee, J.P. (2005) *An introduction to discourse analysis: Theory and method*, Routledge.

Hurst, E. (2010) 'Language in Engineering and the built environment: Examining students' problems and impacts,' *Language*, 1986.

Institute for Inquiry. Exploratorium. (2015) 'Science writing: A tool for learning science and developing language,' www.exploratorium.edu.

Jacobs, C. (2007) 'Towards a critical understanding of the teaching of discipline-specific academic literacies: Making the tacit explicit,' *Journal of Education*, 41: 59–81.

Kelly-Laubscher, R.F. and Luckett, K. (2016) 'Differences in curriculum structure between high school and university biology: The implications for epistemological access,' *Journal of Biological Education*, 50(4): 425–441.

Kelly-Laubscher, R.F., Muna N. and van der Merwe, M. (2017) 'Using the research article as a model for teaching laboratory report writing provides opportunities for development of genre awareness and adoption of new literacy practices,' *English for Specific Purposes*, 48: 1–16.

Kelly-Laubscher, R.F. and van der Merwe, M. (2014) 'An intervention to improve academic literacies in a first year university biology course,' *Critical Studies in Teaching and Learning*, 2(2): 1–23.

Kirby, N.F. (2010) 'Foundation science student performance explained. Insights gained at UKZN,' https://www.assaf.org.za/files/2010/10/Kirby-Performance-explained.pdf (Accessed 28 November 2019).

Kirk, S. (2019) 'Knowledge-orientated perspectives on EAP: Some tools for thinking and practice,' paper presented at the Knowledge in EAP BALEAP Professional Issues Meeting (PIM) University of Northampton, 22 June 2019.

Lee, O. and Fradd, S.H. (2002) 'Instructional congruence to promote science learning and literacy development for linguistic diverse students,' in D.R. Lavoie and W.M. Roth (eds) *Models of Science Preparation. Science & Technology Education Library* (Vol. 13), Springer.

Marshall, D. and Case J.M. (2010) 'd/Discourse in the learning of physics: The design of an introductory physics curriculum,' *African Journal of Research in MST Education*, 14(2): 15–27.

Martin, J.R. (2013) 'Embedded literacy: Knowledge as meaning,' *Linguistics and Education*, 24: 23–37.

Maton, K. (2013) 'Making semantic waves: A key to cumulative knowledge building,' *Linguistics and Education*, 24: 8–22.

Maton, K. (2014a) *Knowledge and knowers: Towards a realist sociology of education*. Routledge.

Maton, K. (2014b) 'A TALL order? Legitimation Code Theory for academic language and learning,' *Journal of Academic Language and Learning*, 8 (3): A34–A48.

Maton, K. and Doran, Y.J. (2017) 'Semantic density: A translation device for revealing complexity of knowledge practices in discourse, part1 – wording,' *Onomázein. Revista semestral de lingüística, filogía y traducción, número especial SFL*, 2017: 46–76.

McNeill, K.L., Lizotte D.J. and Krajcik, J. (2005) 'Identifying teacher practices that support students' explanation in science,' paper presented at the *annual meeting of the American Educational Research Association*, April 2005, Montréal, Canada.

Mouton, M. (2019) 'A case for project based learning to enact semantic waves: Towards cumulative knowledge building,' *Journal of Biological Education*, 54(4): 363–380.

Mouton, M. and Archer, E. (2018) 'Legitimation Code Theory to facilitate the transition from high school to first-year biology,' *Journal of Biological Education*, 53(1): 2–20.

National Research Council. (2007) 'Teaching science as practice,' in R.A. Duschl, H.A. Schweingruber and A.W. Shouse (eds) *Taking science to school: Learning and teaching in grades K–8. Committee of Science Learning, Kindergarten through eighth grade*. The National Academies Press.

Skovholt, K. (2016) 'Establishing scientific discourse in classroom interaction teacher students' orientation to mundane versus technical talk in the school subject Norwegian,' *Scandinavian Journal of Educational Research*, 62(2): 229–244.

Valencia, S. (2014) 'When high school students struggle with textbook reading,' https://www.edutopia.org/blog/students-struggle-with-textbook-reading-sheila-valencia (Accessed 19 July 2018).