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Legitimation code theory to facilitate transition from high school to first-year biology

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ABSTRACT
Institutions of Higher Education have grappled with the predicament of first-year success and epistemological access for years. Recently, a study employed Legitimation Code Theory (LCT) to elucidate why students who performed relatively well in high school biology struggled with the subject in first-year. This study shed valuable light on this problem by revealing that the high school biology curriculum is at a completely different level to the university curriculum. In terms of LCT's Semantics dimension, the high school curriculum displayed little movement from context dependent simpler meanings towards the relatively decontextualised complex meanings, frequently encountered in first-year biology. We argue that the Semantics dimension of LCT also offers a useful tool for restructuring first-year biology curricula to intentionally facilitate a more gradual transition for first-year students. Thus, by explicitly planning teaching activities to gradually increase the range between context dependent simpler meanings and relatively decontextualized complex meanings, the potential of cumulative learning can be optimised. This paper reflects on the process of revising a first-year biology curriculum to contribute to greater epistemological access and cumulative knowledge building.

KEYWORDS
Articulation Gap; Legitimation Code Theory; Semantics dimension; cumulative learning

Introduction

The transition from high school to institutions of higher education is globally regarded as one of the most challenging life experiences that many students will face. We know that the probability of a successful transition is dependent on the student's prior educational and personal experiences and how those equipped them for the demands and expectations of university success (Conley 2007). Kift (2009) articulates a 'transition pedagogy' where first-year curricula and their delivery are aligned and explicit in assisting the current heterogeneous cohorts of first-year students from their previous learning experiences, to the ways of learning in higher education. In this paper, we consider the transition of students from school to first-year biology. We pause at what is known about their previous experiences in school biology and how that may be different from what is expected in first-year and thereafter in higher education. The paper then reflects on the process of how a first-year biology curriculum may be restructured to assist students in making a successful transition from their previous

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learning experiences in biology, by drawing on Legitimation Code Theory (LCT) as a tool for analysis and changing of pedagogy.

South African institutions of higher education have grappled with the quandary of first-year success for years, complicated by the wide range of levels of academic competency across matriculants in the country (Scott, Yeld, and Hendry 2007). Many students from disadvantaged educational backgrounds struggle with the content of first-year curricula and high dropout rates of up to 56% bear witness to this sombre reality (Scott, Yeld, and Hendry 2007; CHE 2013; Shay, Wolff, and Clarence-Fincham 2016). Taking into account the low participation rates among previously disadvantaged groups to begin with, Scott, Yeld, and Hendry (2007) argue that improving the graduate outputs would depend heavily on optimising the outcomes among current student cohorts. However, it is evident that the prevailing system is not effectively addressing this ideal.

One key structural curriculum problem contributing to the low first-year success rate in South Africa is the lack of effective articulation or educational continuity between consecutive educational levels, more specifically between secondary and higher education. Research has shown that students from previously disadvantaged educational backgrounds often lack the sound foundation essential for tertiary studies due to the so-called 'articulation gap' and consequently find it challenging to respond positively to conventional tertiary education programmes (Shay, Wolff, and Clarence-Fincham 2016). Alternative teaching strategies are therefore crucial in recognising and building on existing competences of students (Kift 2009), without preconceptions regarding prior proficiency.

One strategy that aimed to address educational disadvantage and the articulation gap in South Africa was the establishment of foundational provision, also known as Extended Degree Programmes (EDP). These programmes have been implemented in South African universities with the explicit aim to widen access for previously educationally disadvantaged students, and focus mainly on conceptual development and key academic skills in a first foundation year, where after students join the main degree streams (Scott, Yeld, and Hendry 2007). However, even within the foundation year, students may struggle with epistemological access and adjusting to the new educational environment, raising several questions about the efficacy of the initiative (CHE 2013; Shay, Wolff, and Clarence-Fincham 2016).

This paper reports on an amended biology curriculum and pedagogic intervention, evaluated and implemented in an EDP first-year biology module. We reflect on the process as well as how the amended curriculum influences student learning and academic literacy, and contribute to epistemological access for these first-year students.

Background

Kelly-Laubscher and Luckett (2016) reflected on why South African students who performed relatively well in high school biology struggled with the subject in first-year, especially those from previously disadvantaged backgrounds. In the study, they used Legitimation Code Theory (LCT) to compare high school and first year biology textbooks and curricula in terms of semantic gravity (SG) and semantic density (SD). LCT is a sociological toolkit offering a means to research, but also change and shape, among others, teaching practice (Maton 2013, 2014a, 2014b). This is an integrated approach, stemming from a wide range of ideas, with the main contributions coming from the frameworks of Bourdieu's field theory and Bernstein's code theory (Maton 2013, 2014a, 2014b). LCT forms a core part of social realism which sees knowledge as an object, both real and produced socially. It offers a multidimensional conceptual toolkit, wherein the different dimensions can be used to analyse specific sets of organising principles, underlying practises as legitimation codes (Maton 2014b).

The Semantics dimension of LCT regards social fields of practice as semantic structures, which relate to meanings, both cumulatively and individually constructed over time. The organizing principles of these semantic structures can be conceptualised as semantic codes, consisting of semantic gravity (SG) and semantic density (SD) (Figure 1). Semantic gravity is an indication of the degree to which the meaning relates to the context. Semantic gravity can consequently be stronger or weaker along a continuum of strengths. The stronger the semantic gravity, the more the meaning is context dependent

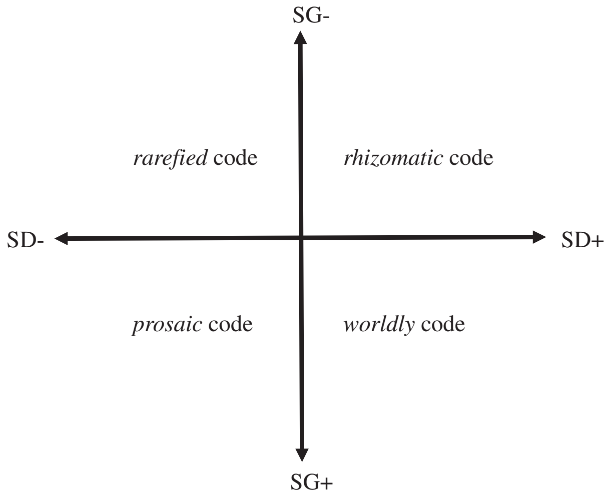

Figure 1. The Semantic plane used in LCT (Maton, 2014b).

and the weaker the semantic gravity, the less the meaning is context dependent and therefore more abstract. In practice therefore, semantic gravity can be 'dynamised' by weakening or strengthening, in other words moving between generalizations and abstractions, and concrete defined cases and examples. Semantic density on the other hand refers to conceptualising the degree of complexity of meaning and can likewise be stronger and weaker along a continuum. With stronger or weaker semantic density, the meaning within the practice is therefore more complex or less complex using simpler terms (Maton 2013, 2014b). Determining the course of strengthening and weakening of semantic gravity and semantic density makes it possible to trace the semantic profile of the practice over time on a semantic plane (Figure 1) or as a wave-like graph (see example in Figure 4(A)). The semantic profile can be compared to the 'pulse' of the knowledge building, where bigger fluctuations on the graph would indicate more movement between stronger and weaker semantic gravity and semantic density. The semantic range represents the degree of movement between the highest and lowest strengths for semantic gravity and semantic density, and thereby gives an indication of how strong or weak the 'pulse' of knowledge building is. The 'ideal pulse' would therefore be where semantic waves are formed in practice, thus shifting between stronger and weaker semantic gravity and semantic density, and therefore variation between stronger and weaker context dependency, as well as weaker and stronger degrees of complexity of meaning. In this context, semantic waves are thus accomplished by the weaving together of different types of semantic codes, which is a key factor in cumulative knowledge building (Maton 2013).

Generally, all educators strive towards cumulative knowledge building where students are enabled to transfer acquired knowledge across contexts (Maton 2009, 2013). This type of learning allows students to build on and integrate new knowledge with past knowledge, across a range of contexts. Segmented learning in contrast, is where the acquired knowledge is strongly tied to the context in which it was learnt and students cannot recognise the knowledge across different contexts. One frequent pitfall towards cumulative knowledge building in teaching practice is where educators introduce a new concept, followed by 'unpacking' the concept using past knowledge and simpler less complex meaning and setting it in an applicable context. However, the problem arises when the same concept is not properly 'repacked' by moving back towards abstraction and stronger semantic density, before the next concept is introduced. This phenomenon is known as the 'down escalator' semantic profile or a sequence of 'downward semantic shifts' (Maton 2013). Pedagogic practises with this profile involves perpetual 'unpacking' of context independent complex concepts using concrete examples and simpler language towards more simple and concrete meanings, but often fail to make the subsequent 'upward semantic shifts' again by 'repacking' back to complex abstract meanings of the concepts, which form parts of the big constellations of meaning in biology. Pedagogic practice can similarly display 'up escalator' semantic profiles where the opposite occur. Both these approaches lead to segmented learning as opposed to cumulative knowledge building.

The Kelly-Laubscher and Luckett (2016) study used LCT to compare a section of the high school and first-year biology curriculum and textbooks in South Africa in terms of semantic gravity and semantic density. They found that the high school biology curriculum exhibited considerably weaker semantic density (less complexity) and covered a significantly smaller range for semantic gravity (remaining mostly contextual). Moreover, when analysing and comparing the high school and first-year textbooks, they discovered that the high school textbook fell into the *prosaic code* of the semantic plane (more contextual and a lower degree of complexity; bottom left hand quadrant; SG+, SD–), whereas the first-year textbook was positioned in the *worldly code* (fairly contextual to abstract and a higher degree of complexity; bottom right quadrant; SG+, SD+; Figure 1). Put simply, these findings therefore revealed that the types of knowledge in these two curricula differ significantly with a rather sudden shift in the degree of complexity of meaning (from weaker to stronger semantic density), also known as epistomological condensation. To complicate matters further, the range for semantic gravity was found to be significantly wider in the university textbook (from more contextual and concrete to abstract and context independent), which contains multiple examples and experiments related to concepts. This is in contrast to the high school textbook, which displays a low semantic flat-line with fewer examples and experiments and thus little or no shifts (movement) on the semantic plane. This approach causes the knowledge to remain locked within its context and therefore constraining cumulative learning and knowledge-building. Significantly higher volumes of subject content in first-year compared to high school, in combination of the factors mentioned above, therefore pose a hurdle to epistemological access for many underprepared first-year students.

Biology and LCT Semantics

In the early days of biology teaching (approximately the 1960s), high school courses tended to be a reluctant blend of botany and zoology, and first-year courses focused more on the needs of prospective medical students, subsequently offering basic physiology, biochemistry and histology, as well as plant morphology and taxonomy. At the time, the discipline was essentially regarded as a descriptive science in the United Kingdom, involving limited research or problem solving opportunities (Jenkins 2016). However, the subject evolved over time and new fields of biology emerged. Authors like Mayr (1996) wrote numerous publications on the topic which distinguish between functional and evolutionary biology. Functional biology includes fields such as morphology, physiology, embryology, histology, ethology, ecology, cellular and molecular biology, as well as agriculture and medicine. Evolutionary biology on the other hand incorporates systematics, phylogeny, comparative biology, historical biogeography, etc. (Bock 2017). Moreover, understanding the basis of scientific investigation and developing the skills to critically interrogate evidence are crucial pillars of the discipline. The abstractness of biology has therefore increased substantially since its early days, evolving to be more mathematical, experimental and focused on the conceptual cellular level of chromosomes and genes. This advancement further infers that the discipline has grown to be conceptually demanding, and therefore progressively more challenging and even inaccessible to under-prepared students (Jenkins 2016).

Educational researchers in chemistry have rationalised the challenges of their discipline by deconstructing the discipline's knowledge in terms of teaching and learning into three levels, the macroscopic, the microscopic and the symbolic, also known as the chemistry triplet. The macro-level applies to concepts and occurrences that are visible to the naked eye, the micro-level to particulate models of matter and the symbolic level to chemical and mathematical symbols and their interrelatedness. According to the authors, expert chemists operate in a matrix where all three levels come into play whereas novices (students) mainly manoeuvre on the macro-level and find the other two levels troublesome to negotiate (Gilbert and Treagust 2009; Talanquer 2011; Blackie 2014). We believe that biology knowledge in terms of teaching and learning can also be considered on similar levels: macro-level, micro-level, molecular level and symbolic level. The macro-level therefore also applies to concepts and occurrences that are visible to the naked eye. However, the micro-level in biology applies to microscopic organisms and structures, the molecular level to particulate models of matter and the symbolic level to chemical symbols, mathematical symbols and their interrelatedness. The same argument of degree of abstraction pertaining to chemistry education can therefore also be applied to teaching and learning in biology where students (novices) may struggle to operate confidently beyond the macro- and micro-levels.

The discipline of biology is similar to other science disciplines which tend to continually move to greater integrating propositions and increasingly more abstract levels. It aims to integrate the exact, rational and methodically principled knowledge across a growing range of seemingly distinct phenomena (Maton 2013). The challenge for biology educators is therefore to enable their students to build up an extended range of specialised biological concept meanings through the language of biology, to be applied or employed to elucidate a wide range of contexts in biology, as well as related fields such as medicine. From a LCT Semantics perspective, traditional biology was mostly situated in the worldly code (more concrete and experimental with a high degree of complexity). However, today's biology ranges between the rhizomatic code for fields such as cellular and molecular biology (with high levels of abstraction and complexity), and also worldly and rhizomatic codes for other fields such as animal or plant form and function (relatively concrete to abstract with a high degree of complexity). Students may therefore find some fields conceptually more challenging than others, as a result of the degree of abstraction.

LCT offers an approach to evaluate teaching and learning practises (Kelly-Laubscher and Luckett 2016) using Semantics. However, there is also a growing body of studies over a range of disciplines using LCT to shape pedagogic practice (Clarence 2016; Georgiou 2016; Kirk 2017). Our study therefore aimed to explore the affordances of the LCT tools, specifically Semantics, to strategically plan how to address the disparities identified by Kelly-Laubscher and Luckett (2016), and the articulation gap and under-preparedness described by various authors (Scott, Yeld, and Hendry 2007; Shay, Wolff, and Clarence-Fincham 2016) in the South African context. We therefore propose that each section of the biology curriculum be designed to explicitly create semantic waves and movement between the prosaic code (SG+, SD−) and worldly code (SG+, SD+) to allow activation of prior knowledge and meet students' knowledge frameworks, but then also gradually up to the rhizomatic code (SG−, SD+) where a considerable part of the current biology concept knowledge lies; a movement from bottom-left to bottom-right and then up to top-right quadrant on the semantic plane. We argue that this sequence of steps will lead to first meeting students' prior knowledge that is more contextual but less complex in meaning, followed by moving to meaning that is still contextual but with a higher degree of complexity, thus facilitating condensation in meaning first but still rather contextualized. Moving from here to more decontextualized meaning with a high degree of complexity may create a more gradual transition for students to negotiate, as opposed to jumping straight from contextual with a low degree of complexity in meaning (their school knowledge) to decontextualized meaning with a high degree of complexity in first-year. We believe that it is common pedagogic practice in the sciences at university level to mostly teach in the rhizomatic code (decontextualized meaning with a high degree of complexity) and that most first-year lecturers lack insight about students' knowledge structures and disciplinary proficiency. Moreover, we further believe that this approach will advance the chances of successful cumulative knowledge building where students should be able to recognise more meaning from previous learning experiences to gradually build on in the future towards the constellations of meaning in the discipline.

Biology is furthermore a discipline that requires the skill of reading and writing on a wide range of topics. Students therefore require a wide scientific background knowledge to enable comprehension of discipline based publications. Macnaught et al. (2013) refers to this skill as 'high stakes reading and learning'. During assessments or scientific writing on the other hand, students are required to use their conceptual knowledge to formulate descriptions, arguments and explanations, also known as 'high stakes writing' (Macnaught et al. 2013). However, students often find it very challenging to bridge the gap between so-called 'high stakes reading and learning' and 'high stakes writing'. Finding ways for students to negotiate semantic waves themselves, in collaboration with the lecturer, may contribute to bridging this gap between 'high stakes reading and learning' and 'high stakes writing' expected in assessments and other scientific writing (Macnaught et al. 2013).

The aim of this study was to explore the affordances of LCT in evaluating and changing the pedagogy and possibly curriculum in an EDP biology module. The first goal was to meet student knowledge frameworks at high school level and then through semantic waves, progressively move towards weaker semantic gravity (higher degree of abstraction) and stronger semantic density (more complexity). The second goal was improved conceptual understanding, facilitated through cumulative knowledge building, where students would be able to build on their past knowledge, but also integrate it with new knowledge, across a wider range of contexts.

Participants

The proposed design approach was evaluated and implemented in an EDP first-year biology module. Eighty-four students were registered for the Biology 146 module in 2016 and 59 in 2017.

The EDP at Stellenbosch University (SU) is offered to students who do not fulfil all the requirements to register for a specific degree. Typically, in the Science faculty, these students have only one symbol in one subject lower than the minimum entry requirements for the traditional three year B.Sc. degree. Their three-year bachelor's degree is therefore spread over four years, where the additional first-year is reserved for foundational modules. The programme aims to broaden access to degree programmes for students from disadvantaged educational backgrounds in South Africa.

Methodology

Learning designs (lesson plans and PowerPoint presentations) for Biology 146 were evaluated with regard to LCT Semantics (Figure 2 and 3). This implies that every lecture was set out in a table form (see an example in Tables 1 and 2) and every topic/concept dealt with was rated in terms of semantic gravity and semantic density using the translation device in Table 3 as a guide to determine the semantic profile. Shortcomings in terms of the semantic profile (a lack of semantic waves and 'semantic flat-lines') were identified (example Figures 4(A) and (B)), where after lesson plans were then amended and expanded to address identified weaknesses (see example in Table 2 and Figures 5(A) and (B)). This process mostly included the incorporation of more examples and experiments to widen the range between context dependent and more decontextualized meanings (semantic gravity) and thereby prevent flat-lines for semantic gravity where meaning often becomes free-floating and 'meaningless' to students. Similarly, to facilitate a slower condensation of conceptual complexity in terms of semantic density, more time was planned to 'unpack' complex concepts using simpler meanings and previously learnt concepts and then 'repacking' these back to the complex, condense meanings of the concepts (see example in Figures 5(A) and (B)). Furthermore, to enact 'semantic flow' between the sections (classes) of the units in the curriculum, successive lectures were planned with the beginning and end to overlap (to link the semantic waves) so that students could easier catch on again and follow the course of lectures. The 'unpacking' and repacking' approach of Maton (2014b), and therefore creating semantic waves for cumulative knowledge building, were the main aims. This approach was followed by evaluating and redesigning the most challenging, more abstract sections of the module, although only examples are presented here.

To gauge whether there was a change in student learning and understanding of concepts, a mixed method approach was employed. Students' conceptual understanding was evaluated by looking at selected formative and summative assessment questions and comparing these to that of the pre-intervention cohorts. Focus group interviews, conducted by an independent professional with randomly selected students, were employed to reflect on students' learning experiences. Adjustments to future cycles have and will be made with the feedback in mind.

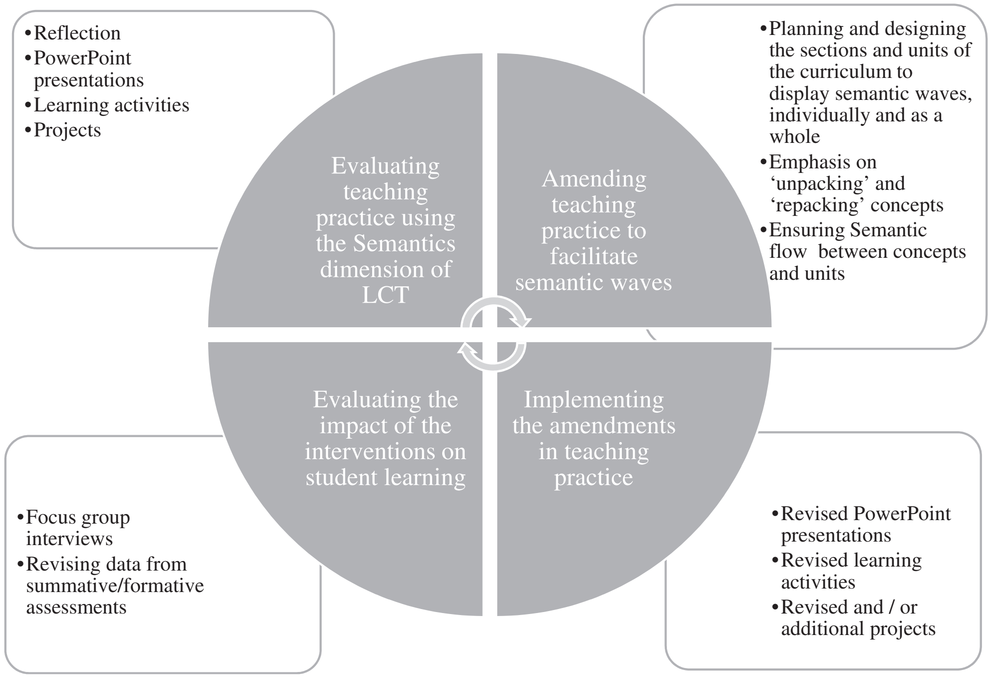

Figure 2. Diagram showing the proposed project design aimed at assessing and amending the curriculum of Biology 146 to facilitate cumulative learning for first-year students. The centre disk represents the main aims and the neighbouring blocks represent the activities.

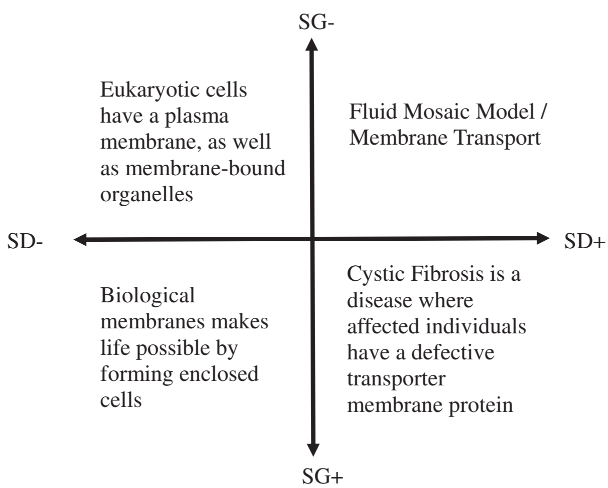

Figure 3. Semantic plane showing the application of the Semantics dimension of LCT on the topic of membrane structure and function.

Evaluating teaching practice

After critically evaluating general pre-intervention teaching practice using the Semantics dimension of LCT (before amendments), we realised the following in general:

- Although context and examples have frequently been included to elucidate biological concepts before, it was generally done at the start of the lectures to establish significance and an example

Table 1. The layout of the 'membrane structure' lecture before redesign (see Figure 4).

	Lecture sections	Description
1	Intro General	Membranes makes life possible by forming enclosed cells.
2	Intro Context	Found in single cells and multicellular organisms. Where found in cells?
3	Intro Context	Normal functioning of critical importance.
4	Intro Context	Introduction of CF Patient video.
5	Intro Context	Introduction of CF Cell Level video.
6	Intro Context	Explain condition, symptoms and cause of CF, causing defective membrane integrity.
7	Structure*	Explain the structure and components using a diagram.
8	Component 1*	Phospholipid bi-layer.
9	Component 1	Phospholipid matrix.
10	Component 1*	Function and permeability of phospholipid bi-layer.
11	Component 2*	Membrane-bound proteins.
12	Component 2	Association of membrane-bound proteins with phospholipid bi-layer.
13	Component 2*	Types and functions of membrane-bound proteins.
14	Component 3*	Cholesterol molecules.
15	Component 3	Association of cholesterol molecules with phospholipid molecules in bi-layer.
16	Component 3	Function of cholesterol w.r.t. permeability of phospholipid bi-layer.
17	Structure	Explain the structure and components using a diagram.
18	Clicker**	Revision and application of concepts.

*Concepts; **Blended learning activity.

Table 2. The layout of the 'membrane structure' lecture after redesign (see Figure 5).

	Lecture sections	Description
1	Intro General	Membranes makes life possible by forming enclosed cells.
2	Intro Context	Found in single cells and multicellular organisms. Where found in cells?
3	Intro Context	Normal functioning of critical importance.
4	Intro Context	Introduction of CF Patient video.
5	Intro Context	Introduction of CF Cell Level video.
6	Intro Context	Explain condition, symptoms and cause of CF, causing defective membrane integrity.
7	Structure*	Explain the structure and components using a diagram.
8	Component 1*	Phospholipid bi-layer.
9	Component 1	Structure and nature of phospholipids.
10	Component 1	Phospholipid matrix.
11	Component 1*	Function and permeability of phospholipid bi-layer.
12	Component 1	Importance of intact phospholipid bi-layer: Clip of amoeba.
13	Component 2*	Membrane-bound proteins.
14	Component 2	Structure and nature of membrane-bound proteins.
15	Component 2	Association of membrane-bound proteins with phospholipid bi-layer.
16	Component 2*	Types and functions of membrane-bound proteins.
17	Component 2	Go back to the CF example to highlight the importance.
18	Component 3*	Cholesterol molecules.
19	Component 3	Structure and nature of cholesterol molecules.
20	Component 3	Association of cholesterol molecules with phospholipid molecules in bi-layer.
21	Component 3	Function of cholesterol w.r.t. permeability of phospholipid bi-layer.
22	Structure	Explain the structure and components using a diagram.
23	Context	Normal functioning of critical importance summarise in plain terms.
24	Podcast**	Revision and summary of concepts.
25	Clicker**	Revision and application of concepts.

*Concepts; **Blended learning activities.

(context) of where the concepts apply to the real world. This strategy contributed to adding context to often very abstract concepts and thereby strengthened the semantic gravity. However, by only starting lectures this way and often not referring back to the original example or previous knowledge from earlier lectures, the range for semantic gravity remained limited. Also, the semantic profile of lectures mostly varied between complex context dependent and complex context independent meanings (thus the worldly and rhizomatic codes), showing little semantic movement. It was therefore clear that the pre-intervention lectures did not reach down the semantic

Table 3. The translation device for semantic gravity and semantic density employed to evaluate lesson plans.

Concrete experiments and examples, e.g. diseases	SG++	SD−	General everyday language
Examples of significance	↑	↑	General information about certain examples/ structures/diseases/videos
Information about general abstract concepts, e.g. What is life?			Concepts known from school curriculum
Previously learnt context independent concepts			Previously learnt (FY) concepts Scientific language e.g. symptoms
New context independent concepts: Components of structures, structures, processes			New concepts: Components of structures
			New concepts: Structures
			New concepts: Processes/Complex structures
	↓	↓	
	SG−	SD++	

scale to the students' previous learning experiences, which once again highlighted the articulation gap. It thereby confirmed suspicions that we as lecturers have false preconceptions regarding the prior knowledge and skills proficiency of our students, as we wrongfully assume that they are 'with us' at this level of abstraction. We therefore realised that during lectures dealing with complex context independent concepts, significance and relevance should be established using examples. However, there after semantic waves should be generated by weakening and strengthening the semantic density, as well as referring back to the original example, prior knowledge that applies, as well as others relevant examples to perpetually strengthen and weaken the semantic gravity.

- Biological concepts were explained and 'unpacked', although not always adequately using simpler and more familiar meanings (weaker semantic density) accompanied by a wider range of examples and contexts (towards stronger semantic gravity). Also, the concepts were then not always 'repacked' back to the complex, context independent meanings (weaker semantic gravity and stronger semantic density), thus reaching higher up the semantic scale. This in all probability led to the so-called 'down escalator' profile as opposed to semantic waves. According to Maton (2014b), this profile is very common in classroom practice and educators do not reach back up the semantic scale to the type of knowledge needed for success in higher education.

Amendments to the teaching strategy were therefore aimed to address these phenomena.

During the process of evaluating the course material and teaching practice, the need for an additional integrative group project was recognised and consequently introduced, aimed specifically at expanding the semantic range of the students' biology knowledge frameworks and networks. This assignment, the 'Power of Poison Group Project', intended to integrate several of the theoretical core concepts dealt with during the module's class work. The aim was for students to discover the wide range of theoretical concept applications and contexts in the mechanisms and effects of a range of poisons and venoms on the cells of living organisms. Students worked in groups of four and each group drew the name of a unique poison or venom. The group then had to research and present their poison/venom to the lecturer and their peers in class using a PowerPoint presentation. To add to this learning experience, students were required to assess the presentations of their fellow student groups.

Redesigned lesson plans

Both example 1 and 2 presented here are abstract topics in biology, cellular and molecular biology, as well as genetics, and the core concepts are therefore situated in the rhizomatic code on the Semantic plane. We know from literature that the students' concepts knowledge brought from school is far

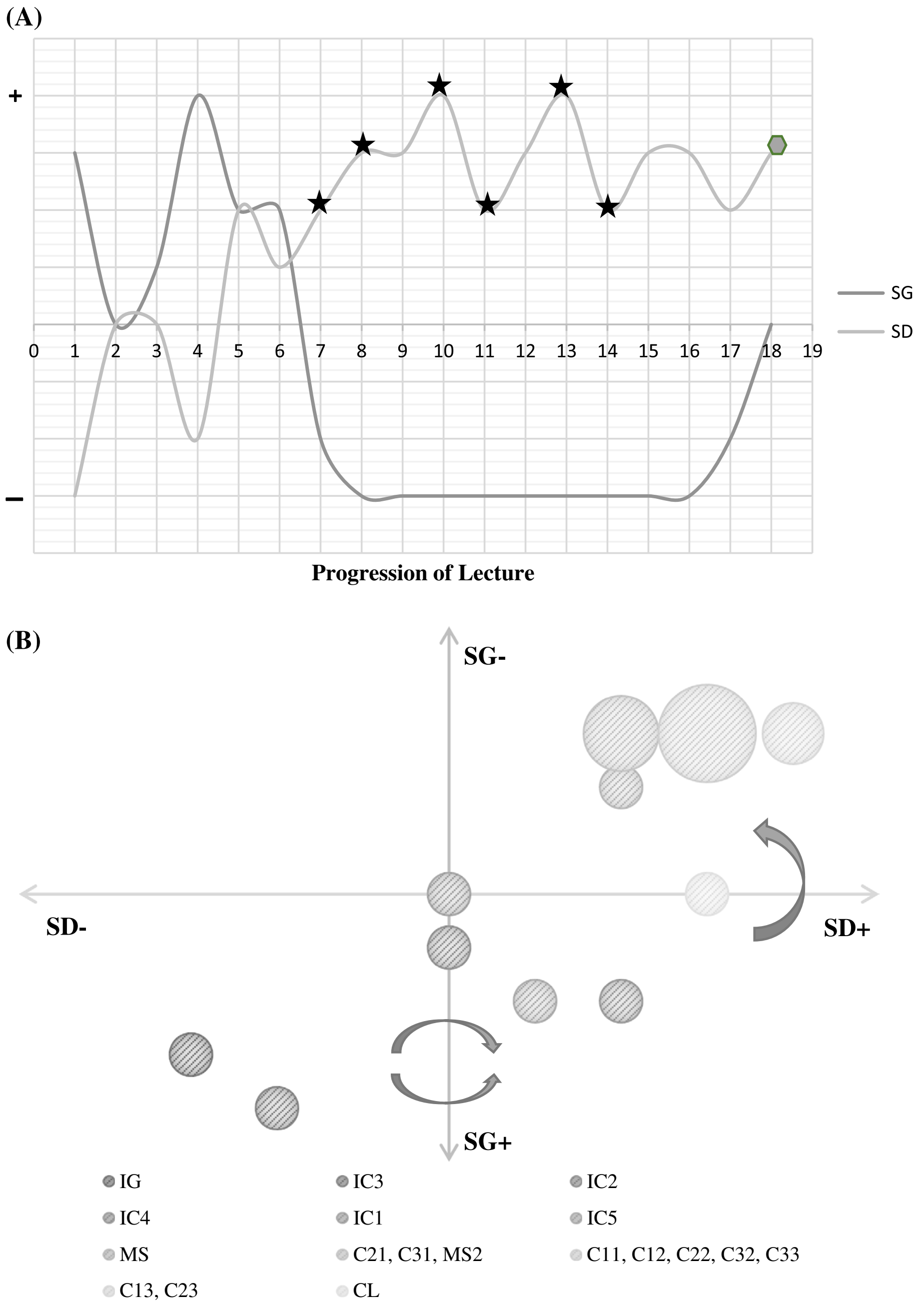

Figure 4. (A) and (B) The Semantic profile of the initial lesson plan dealing with biological membrane structure. 4(A) Stars in the graph represent concepts introduced during class time and the hexagon the blended learning activity (see Table 1). 4(B) The Semantic plane showing the codes represented during the lecture, as well as movement between the quadrants. The bubble size is relative to the time spent.

removed from the rhizomatic code and generally falls into the prosaic code and that a strategy was needed to assist students in narrowing this gap between school and first-year. The aim was therefore to evaluate existing lesson plans using the Semantics dimension of LCT. Weaknesses (semantic flat-lines) were identified mostly where the lectures persistently included complex, context independent

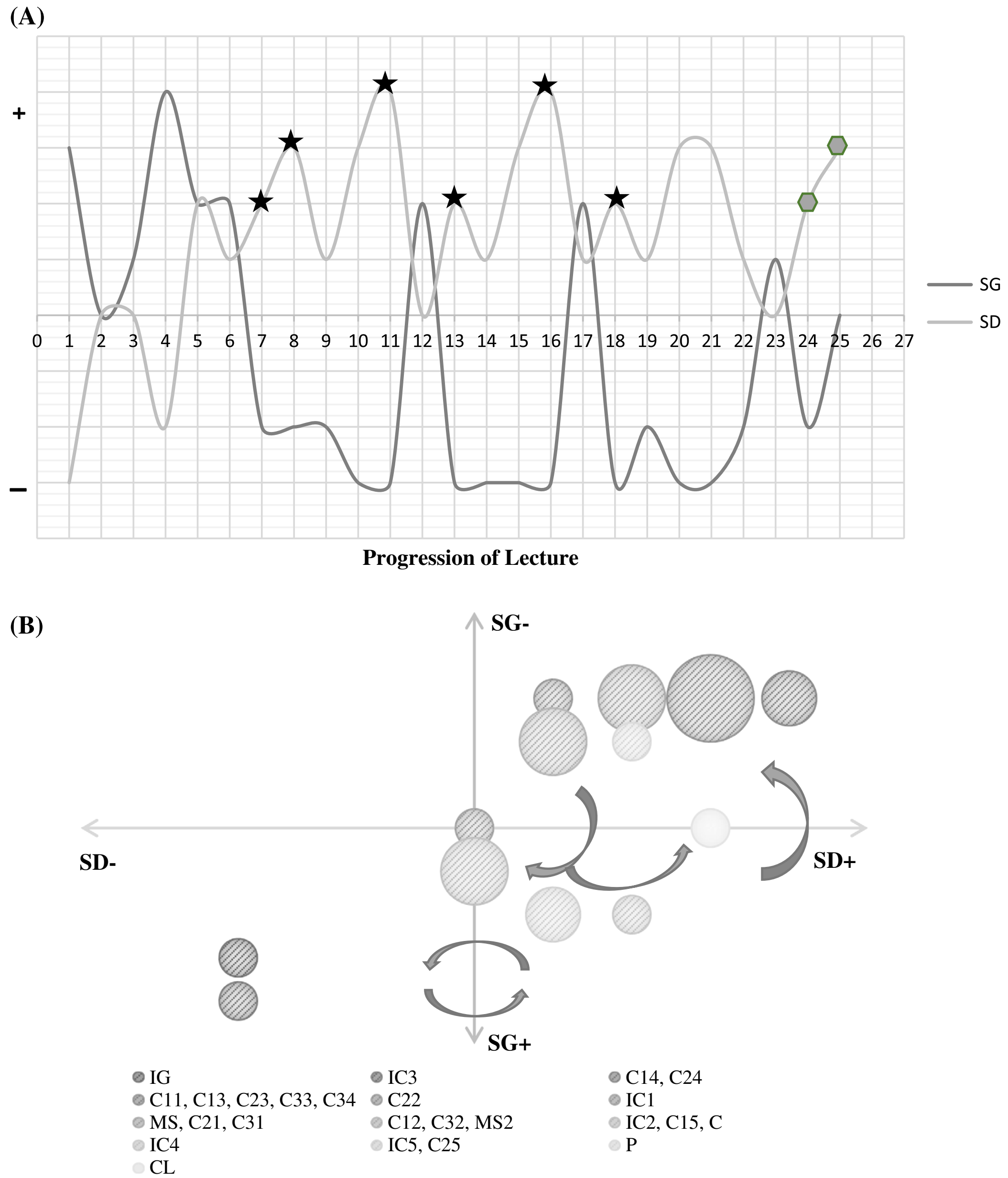

Figure 5. (A) & (B) The Semantic profile of the revised lesson plan dealing with biological membrane structure. 5(A). Stars in the graph represent concepts introduced during class time and the hexagons the blended learning activities (see Table 2). 5(B). The Semantic plane showing the codes represented during the lecture, as well as movement between the quadrants. The bubble size is relative to the time spent.

concepts (in the rhizomatic code), not taking the students' current knowledge structure into account (mostly in the prosaic code). Consequently, lesson plans were tacitly shaped to facilitate semantic waves by perpetually 'unpacking' and 'repacking' these concepts by including more simple familiar explanations and contexts (thus perpetual movement between the prosaic, worldly and rhizomatic codes). This approach was thus intended to gradually assist students in making the shift from their previous biology learning experiences to learning biology in higher education.

Example 1

The first topic presented here, as 'before' and 'after' redesign, is the 'membrane structure' lesson plan which forms the first part of a unit of lectures that deals with biological membranes and transport of molecules across these membranes (Figure 3, 4 and 5, Tables 1 & 2). In previous years, we found that students grappled with comprehension of the 'transport' section because their understanding of the structure itself was still lacking after the lecture, even with the inclusion of context and a real life example. A deep understanding of the form and function of each individual component is pivotal for the subsequent lectures dealing with transport of substances across these biological membranes.

Figure 3 shows how the notions of semantic gravity and semantic density were applied to the analysis and planning of this lecture to create semantic waves and more movement between the codes. This section starts with a general introduction in the prosaic code (SG+, SD−) dealing with the general occurrence and functions of biological membranes in all living organisms and how these structures are responsible for the enclosure of living cells (Figure 4(A) & 5(A)). A specific example of a patient with cystic fibrosis is brought in at this point to establish the crucial role and normal functioning of this structure in the maintenance of 'normal/healthy' life (SG+, SD+; worldly code). This is followed by elucidating the structure of membranes by zooming into each individual molecular component (SG−, SD+; rhizomatic code; Figure 4 & 5). Each component is discussed in terms of molecular structure, consequent 'nature' and function, also referring back to prior sections of the curriculum where these topics were dealt with (movement between the worldly and rhizomatic code).

In the redesigned version (Figure 5(A)) more time was spent to 'unpack and repack' each membrane component thoroughly, including the use of simpler words and referring back to past lectures and knowledge. In this section, semantic density was therefore continually weakened by using familiar terms and simpler explanations and then strengthened again by moving back to the newly introduced abstract, complex concepts and terms (SD+). A pre-intervention SG flat-line (Figure 4(A)) was addressed by referring back to the cystic fibrosis example used during the introduction, as well as the example of an amoeba to illustrate the importance of sustained membrane integrity (Figure 5(A)). Finally, all components discussed were 'repacked' by reviewing a diagram of a biological membrane (Figure 5(A)) with weaker semantic gravity (SG−) and stronger semantic density (SD++).

The face to face class time was followed up with two blended learning activities (Figure 5(A), hexagons): a podcast summarising the most important concepts again (SG−, SD+), as well as an online clicker activity with questions to review the core concepts (SG−, SD+), similar to what would be expected in summative assessments. We believe that this amended lesson plan displays more evident/conscious semantic waves and allows building on prior knowledge. Knowledge is also iteratively transformed between relatively decontextualized, complex, abstract meanings and simpler context dependent meanings. Figures 4(B) and 5(B) show how the redesigned lecture displays more movement and shifts between the worldly and rhizomatic codes than before.

Example 2

The second example presented here (Figure 6 & 7) is the 'DNA replication' lesson plan which forms part of a unit of lectures that deals with the Central Dogma. The concept theory behind DNA replication includes the working of several key enzymes which contribute uniquely to facilitate the process of replication. Furthermore, a deep understanding of the basic theory behind DNA form and function is vital to grasp the processes involved during replication and related processes. Over the years, we have found that students have trouble understanding several core concepts, which ultimately leads to poor understanding of the unique roles of each key enzyme during the process. Although the theory behind this topic appears to be basic, we have found that blended learning tools such as podcasts and Android applications assist very constructively with the conventional methods of teaching. In this example, the inclusion of a blended learning approach in addition to class lectures was found to

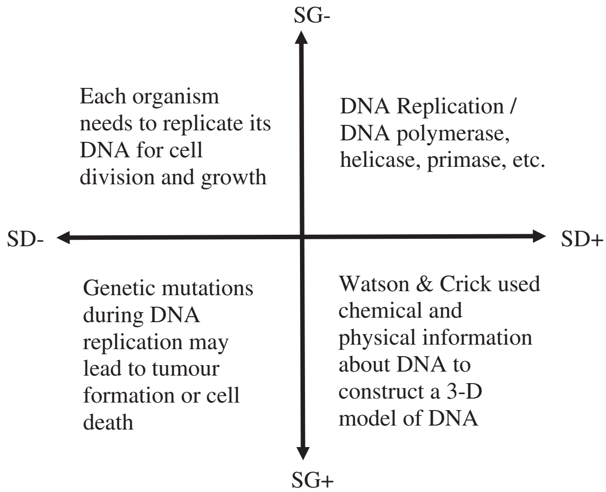

Figure 6. Cartesian plane showing the application of the Semantics dimension of LCT on the topic of DNA replication.

contribute to linking concepts and/or biological processes and to contribute to the 'repacking' and therefore semantic waves, as well as semantic flow.

Figure 7 shows the semantic profile for the DNA replication lecture. The entire process of DNA replication has been broken down into successive sections based on the key enzymes and their unique contributions to the process (for example, helicase, gyrase and the single stranded binding proteins with DNA replication initiation). Once again, the 'unpacking and repacking' approach was used to navigate between concepts with stronger semantic density, such as the terms, concepts and definitions, and stronger semantic gravity, such as experimental work and theory in context, such as a experiments and work done by Watson and Crick, as well as Meselson and Stahl (Figure 7, bottom right quadrant). After each section dealing with a specific enzyme or group of enzymes, a podcast was employed (SG–, SD+) to summarise the previous concepts of the lecture before continuing to a new section falling in the rhizomatic code (Figure 7). Each section was therefore explained using both stronger and weaker semantic gravity, as well as stronger and weaker semantic density, followed by re-packing using the podcasts.

Finally, an Android application was used to facilitate visualisation and finally 'repack' the complete process of DNA replication through revision, interaction and assessment, also promoting student engagement, collaborative learning, activation of past knowledge and cumulative knowledge building, taking them once more between the worldly and the rhizomatic codes (Figure 7). Using such visualization for 'repacking' can be compared to using concept mapping which was found to further promote the processing and synthesis of concept knowledge (Kinchin 2017). From our analysis and Figure 7, we have realised that we can further explore incorporating more real life examples such as cancer and congenital birth defects to further elucidate this topic and move more into the prosaic code and rarefied code. Weakening the semantic density in this way might help students to anchor their new knowledge in a wider semantic range.

Integrative group assignment

The amended curriculum aims for each section of the curriculum to explicitly create semantic waves and movement between the prosaic code (SG+, SD–) and worldly code (SG+, SD+) to allow activation of prior knowledge, but then also up to the rhizomatic code (SG–, SD+); a movement from bottom-left to bottom-right and then up to top-right on the semantic plane. To further kindle cumulative knowledge-building, we finally included an additional integrative summative assessment, aimed

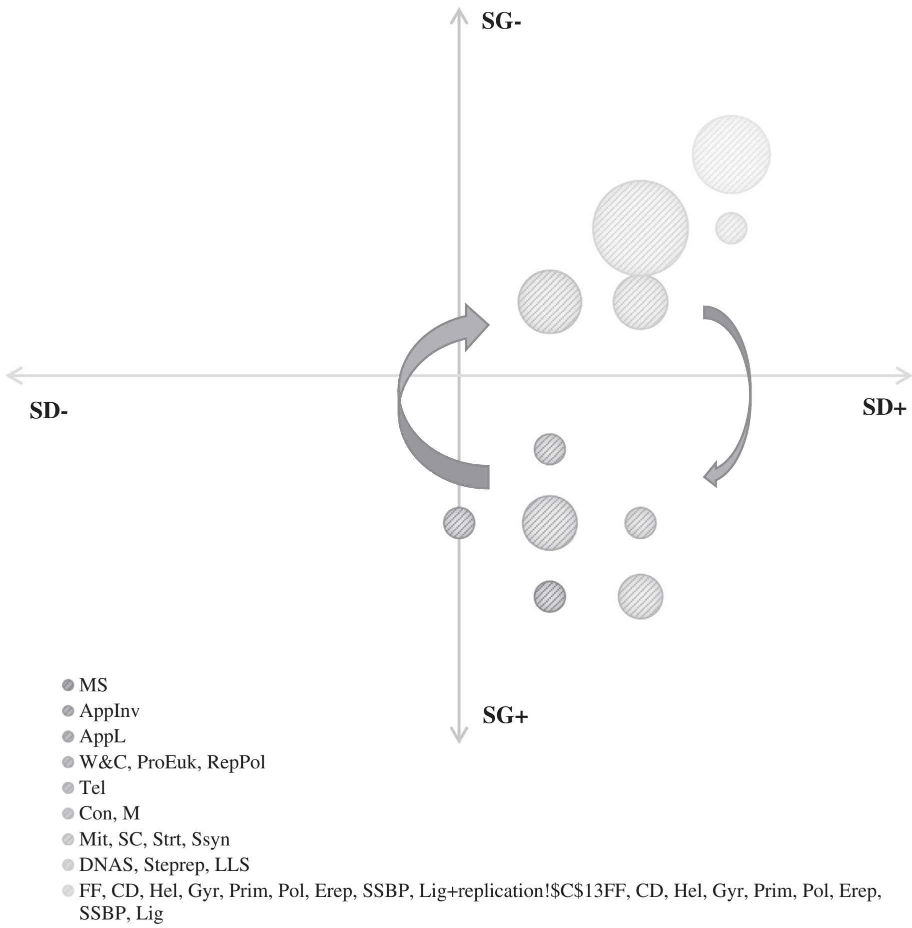

Figure 7. The Semantic profile of the revised lesson plan dealing with DNA replication plotted on a Cartesian plane showing the codes represented during the lecture, as well as movement between the Semantic codes. The bubble size is relative to the time spent.

specifically at further expanding the semantic range of the student's biology knowledge in the form of a collaborative group assignment.

This integrative assignment, known as the 'Power of Poison Group Project', is intended to integrate several of the theoretical core concepts dealt with in the class work, and placing these in a wide range of real life contexts. The aim is for students to 'discover' the wide range of applications/contexts, and where and how these theoretical concepts taught during the semester apply. This is accomplished by researching the mechanisms and effects of a range of poisons/venoms on the cells of living organisms/victims. It is further intended to generate movement of the student's knowledge between the prosaic code (SG+, SD−) and worldly code (SG+, SD+) to allow activation of prior knowledge, but then also up to the rhizomatic code (SG−, SD+) on the Semantic plane (Figure 8). Moreover, the assignment envisions students will not only learn from their own topics (toxin/venom) but also the topics of their peers, since they are required to assess their peer's assignment presentations to further widen the semantic range of the concepts learnt.

A typical student's presentation starts with an introduction to the toxin/venom and where it originates from e.g. black mamba poison (SG+, SD−; Figure 8). Students then elaborate on the origin, e.g. the black mamba, its habitat, nature, etc. (SG+, SD− to SG+, SD+). They would then move on to the toxin/poison and describe its molecular structure and other features (SG−, SD+). Finally, they are required to move toward the effect of the venom/toxin on cellular level and explain the exact

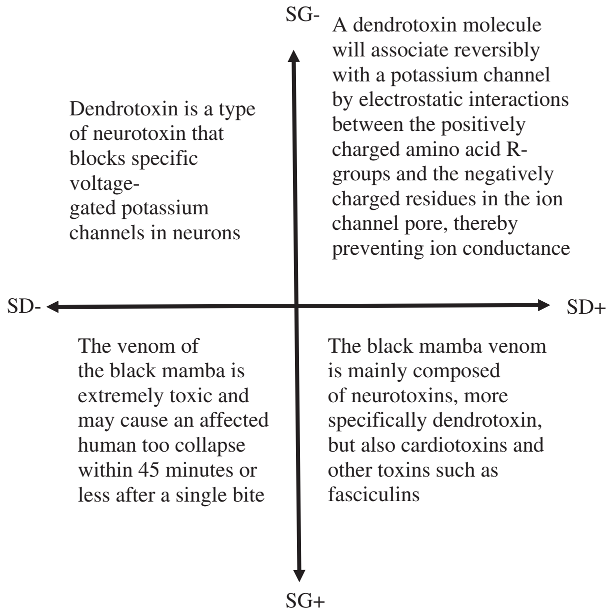

Figure 8. Cartesian plane showing the application of Semantics on the example of a student project on black mamba venom.

mechanisms and/or effects on cellular activities (SG–, SD– to SG–, SD+). Students are therefore required to create semantic waves and movement themselves between the prosaic code (SG+, SD–), the rarefied code (SG–, SD–) and worldly code (SG+, SD+), but then also up to the rhizomatic code (SG–, SD+) during their presentations; a movement from bottom-left and top-left to bottom-right and then up to top-right on the semantic plane (Figure 8). Movement through an even wider semantic range is promoted by then peer assessing all the other peer groups' presentations, which take students then through the wider semantic range multiple times. During a next round of analysis, we plan to evaluate the students' presentations with regard to movement on the semantic plane and the semantic range that they manage to negotiate.

Results and feedback

Student feedback from focus group interviews highlighted the articulation gap between matric and first-year in higher education, as well as the perception of under-preparedness among students with the following comments: 'I came into biology feeling very confident but quickly realized how different it was! I did not realize that biology was so chemical, even the DNA! It was a lot simpler in school.'; 'It was a shock coming here (university)! A big shock!'; 'Secondary education does not prepare you well for university!'; 'At school, a (biology) topic had two new words (terms) to remember. At university it has two hundred!' The differences between curricula in terms of SG and SD are further highlighted by a comment such as this: 'School biology is a lot different. In school they told us that we did not need to remember all the difficult names, like enzyme names. So, the only thing that school biology helps you with is that stuff sounds familiar. But there is so much more that you do not realize that is going on when doing school biology!'

Comparing the conceptual understanding of students in summative assessments of the 'before' and 'after' intervention cohorts, showed that the understanding of the students improved by using semantic waves in lectures and lesson plans (Figures 9 & 10). The section of the work described in Example 1 is represented by the Scatterplot in Figure 9 which shows the noteworthy improvement in the student's understanding of general membrane structure with the implementation of semantic waves in the lesson

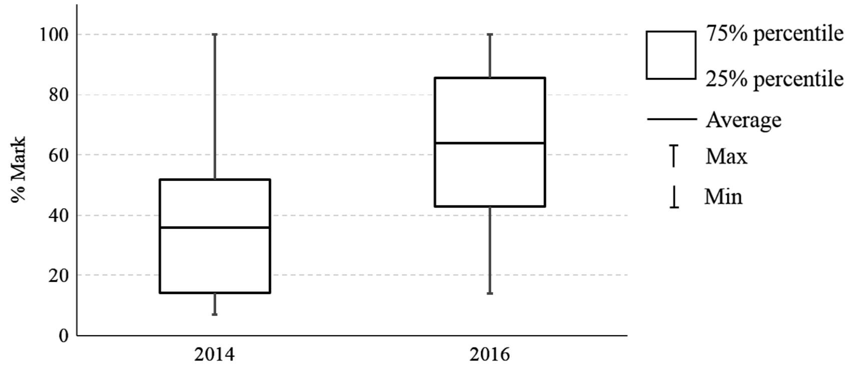

Figure 9. Box and Whisker plot indicating student conceptual understanding of Example 1 using summative assessment questions of the 2014 (n = 109) and 2016 (n = 83) student cohorts. The average mark of the 2014 cohort was 33.4%, in comparison to the 60.9% of the 2016 cohort.

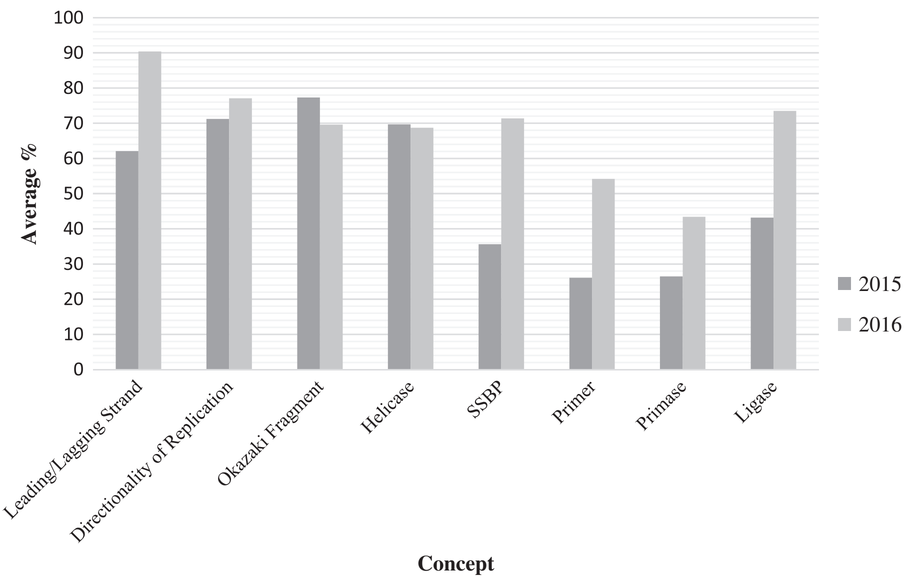

Figure 10. Evaluation of conceptual understanding of Example 2 using summative assessment questions of the 2015 (n = 71) and 2016 (n = 83) student cohorts.

plan. The students' general conceptual understanding of DNA replication is presented in Figure 10 and improved insight was observed for many challenging concepts. Although more research needs to be done, promising trends have been observed when comparing similar question assessments between the pre- and post-intervention cohorts.

The integrative group assignment and assessment turned out to be a big success with regard to our aim of widening semantic range and joint construction, and had a surprisingly positive effect on students' attitudes towards biology learning. During the focus group interviews with the independent reviewer, a lively conversation occurred where the feedback revealed that the students connected a broad range of concept theory with a wide range of applications/contexts (a wider semantic range), and even had fun while doing so. The following comments by students showed how students were able to make connections between the concept theory (SG−, SD+) and a wide range of applications and contexts (SG+, SD− to SD+): 'It was a learning experience. We got the toxin bisphenol A, a poison that we consume every day and we learnt so much about it! It was also very interesting to learn about the other groups' poisons!' Another student stated: 'I never knew why toxins are poisonous, like a neurotoxin for example. Now I realize how it affects the membranes of the cells and it makes a lot more sense now!' This student said: 'I do not like public speaking but it made us learn so much from one another. We could also ask questions. I now know how and where the toxins work on the cells!' Students were able to identify differences and similarities: 'Our toxins were different but also had things (mechanisms) in common and then I would realize, oh, I know that because it works similar to my poison. It is very cool understanding and I look at the world differently now!'

Discussion

The gap between students' knowledge and skills, and what is expected from them in higher education, but also how to overcome this problem has been conversed in a number of studies (Clarence 2016; Georgiou 2016; Kelly-Laubscher and Luckett 2016; Kirk 2017). Kelly-Laubscher and Luckett's (2016) study used LCT to reveal how the school biology curriculum tended to display a low semantic flat-line profile and was mostly working in the bottom left quadrant of the semantic plane. In contrast and unaware of the level of students' concept knowledge, and although intended to 'raise the theoretical bar', our prior teaching approach also leant towards semantic flat-lines, however, predominantly a high flat-line in the top right hand quadrant (rhizomatic code) of the semantic plane. As lecturers, we often presume that by using the appropriate scientific concept terminology, students will learn the language of the discipline and with it, a degree of scientific reasoning. However, after using the LCT Semantics tool for analysis, we realised that this strategy may have led to epistemological access being impeded for many, and even more so for underprepared students, due to the consistent abstractness of the concept theory in lectures being so far removed from their previous learning experiences in the subject. These two approaches are totally disjointed as corroborated by student feedback, reporting feelings of 'shock' coming into first-year biology from the school curriculum. Moreover, both these teaching approaches lead to the knowledge in these curricula remaining locked in a limited context. In other words, the knowledge is strongly coupled with its context and therefore only meaningful within that context, which leads to 'segmented' learning (Maton 2009, 2013). Students may therefore not be able to recognise and build on past knowledge in different and new contexts, causing new knowledge and skills to simply accumulate alongside past knowledge. Maton (2014b) reiterates the problem by arguing that most teaching approaches are 'context dependent or free floating', thereby splitting data from theory.

Using the Semantics tool of LCT, this study revealed that to facilitate cumulative learning in first-year curricula, more effort should be made to meet students' current concept knowledge (in the bottom left hand corner of the semantic plane) from their previous learning experiences. Lesson plans should explicitly be designed to then gradually and progressively move towards the higher levels of complexity and abstraction, as well as wider ranges of contexts of the curricula in higher education (the bottom right and top right hand quadrants of the semantic plane). This can be achieved by employing semantic waves in teaching practice as described by Maton (2013), with the intent to perpetually transform the knowledge between the simpler context dependent meanings and the relatively decontextualized, complex, abstract meanings. This approach will assist students to make the necessary links with the school knowledge they brought with them into higher education. The semantic gravity and semantic density are therefore strengthened and weakened in cycles (waves) as the lecturer aims to move gradually more towards the top and bottom right hand quadrants, characteristic of first year curricula. Furthermore, we believe that the 'unpacking', but also 'repacking' approach of semantic waves in the redesigned lesson plans assist learners to make the move towards narrowing the gap between the relatively decontextualized, complex abstract meanings and the more simple, context dependent meanings. This approach further helps students to connect subject theory to examples and contexts, other than only the examples mentioned in class and also to connect to existing knowledge frameworks to new subject knowledge.

In the Biology 146 module, the LCT Semantics tool further revealed the need for learning activities to integrate as many of the concepts taught through the semester, placed in a wide spectrum of contexts and thus widening the range for semantic gravity. It became clear that the students needed to be exposed to wider range of contexts for the concepts in the curriculum to gradually narrow the gap towards learning in first-year biology. A thoughtfully designed student project (with LCT Semantics in mind) was introduced for this purpose. Completely unaware of LCT, this initiative steers students to move through all four of the quadrants on the semantic plane while placing many abstract core concepts from the top right quadrant into a wide range of contexts in the bottom right and left hand quadrants. A preliminary analysis showed that most groups made use of the two left quadrants as well, in their introductions and conclusions, although a detailed analysis of this project will follow in the next cycle. This project is therefore an excellent implicit initiative for cumulative knowledge building which assembles new knowledge and give new meanings and contexts to past and new biology knowledge.

Summative assessments in the Biology 146 module usually consist of shorter and longer questions where students are required to formulate and write answers to explain a certain structure, process, mechanism, etc. We believe that this type of discourse is the first step in learning to write in the language of biology and science. It is considerably more challenging to formulate an answer using the correct terminology and reasoning, than to recognise the familiar appearing terms in a multiple choice question, even when it requires some analytical reasoning. Macnaught et al. (2013) suggests that lecturers engage in joint construction with students to assist them in learning the linguistic skills necessary for high stakes writing. This is a need that we have identified in our assessments that we would like to address in the cohorts to come. The integrative group project contributed to students' mastery of the much needed linguistic skills to express themselves using the appropriate concept terms in biology. However, a lot more needs to be done in this area.

To conclude, the LCT Semantics tool proved very effective to analyse and then redesign lesson plans to assist first year biology students to narrow the gap between their previous learning experiences in school and learning biology in first-year. Lesson plans and curricula should aim to facilitate semantic waves to meet the current student concept knowledge and then gradually move towards the complex concrete and abstract decontextualized concepts characteristic of biology in higher education, ultimately leading to cumulative knowledge building (Maton 2013). This approach presents a pivotal key to bridging the gap between the school and university biology curricula, but also the articulation gap in general. Blackie (2014) argues that weakening SG is more challenging in chemistry teaching than strengthening it and I have to corroborate this perspective. It is extremely challenging to create such semantic waves when simply lecturing subject content and therefore requires thoughtful effort and planning. However, our explorations showed that students' learning experiences and conceptual understanding certainly benefit noticeably when investing in this approach and would therefore be well worth exploring further.

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