11 Supporting the transition from first to second-year Mathematics using Legitimation Code Theory

Honjiswa Conana, Deon Solomons, and Delia Marshall

Introduction

The transition from first to second year is identified as a challenge for many students in undergraduate programmes around the world (see, for example, Hunter *et al.* 2010 in the USA context; Yorke 2015 in the UK context). Yet, there is surprisingly little research on this transition, with most studies focusing either on students' experiences of the first year or on students' exit-level outcomes. In South Africa, likewise, concerns about transition tend to be concentrated at the transition from school to first-year university. However, studies have argued that there are key 'epistemic transitions' (Council on Higher Education (CHE) 2013) throughout the undergraduate degree that need pedagogical attention.

In this chapter, we illustrate how concepts from Legitimation Code Theory (LCT; Maton 2014) were used to develop insights into the challenges that STEM students face in making the transition to second year. These insights then were used to frame an educational intervention in second-year Mathematics, and this chapter reports on the impact this intervention had on students' learning.

Context of the study

This study took place in the Faculty of Natural Sciences at an historically black South African university. Many of the students are first-generation students in higher education, meaning that their parents/guardians had not attended a tertiary institution. About a third of the first-year intake of BSc students is placed in an extended curriculum programme (ECP). This ECP is a four-year BSc degree, which essentially enables students to complete the first year of their BSc degree over two years, with foundation provision embedded in Physics and Mathematics courses (including strengthening conceptual understanding, strengthening academic literacy in engaging with science texts, etc.). Despite the extensive foundational provision of the ECP, which aimed to give students a solid foundation in Physics and Mathematics, students' transition to second-year Physics and Mathematics remained an ongoing challenge. Student motivation appeared to decline in second year,

DOI: 10.4324/9781003055549-15

accompanied by poor pass rates; this was the case both for ECP students and for those entering second year via the regular three-year BSc route. One obvious reason for the students' transition challenges is that the second year Physics and Mathematics courses become more mathematically demanding. In addition, students are required to apply the Mathematics learning from their Mathematics courses to their Physics courses, which many find challenging (Bing and Redish 2009).

In order to better understand students' transition challenges, first- and second-year Physics and Mathematics classes were observed and interviews conducted with second-year students. Tools from LCT were useful in characterizing the teaching practices in these courses and in beginning to identify some of the obstacles that students were experiencing in making the transition to second year.

Legitimation Code Theory as a tool for thinking about transition to second year

LCT is a sociological 'toolkit' (Maton 2014: 15) which integrates and extends key concepts from, among others, the work of sociologists Basil Bernstein and Pierre Bourdieu, including Bernstein's code theory, knowledge structures and pedagogic device (Bernstein 1996), and Bourdieu's concepts of field theory, capital and habitus (Bourdieu 1994); for a more detailed account of the develop of LCT, see Maton (2014). LCT comprises three active dimensions or sets of concepts that explore different organizing principles underlying practices, dispositions and context. For the purposes of this chapter, we focus on two dimensions: Semantics and Specialization. Concepts from the Semantics and Specialization dimensions provide useful tools to characterize STEM knowledge structures and practices, in order to begin to tease out some of the transition challenges that students experience. In this section, we provide a brief overview of the key concepts from the Semantics and Specialization dimensions used in our study.

Concepts from Semantics for thinking about transition to second year

Concepts from the Semantics dimension of LCT (Maton 2009, 2013, 2014, 2020) provide useful conceptual tools for allowing us to analyze the knowledge structure and practices of STEM disciplines. *Semantic gravity* is defined as the extent to which meaning 'is related to its context of acquisition or use' (Maton 2009: 46). When semantic gravity is weaker, meaning is less dependent on its context. In other words, semantic gravity is related to the degree of abstraction. For example, the decontextualized, abstract Physics concept of 'force' can be applied to a wide range of specific contexts, ranging from vast galaxies to tiny atoms.

Semantic density describes the complexity of meanings and is defined as the extent to which meaning is concentrated or condensed within symbols (a term, concept, phrase, expression, gesture, etc.) (Maton 2014). In STEM disciplines, meaning is often condensed within nominalizations (scientific words or phrases that are dense in meaning), such as ‘acceleration’ (Physics), ‘photosynthesis’ (Biology). A great deal of information is also condensed into graphs, symbols, diagrams and mathematical equations.

To visualize the relative strengths of semantic gravity (SG) and semantic density (SD) over time, Maton (2013, 2014, 2020) developed the analytical method of *semantic profiling*. This indicates in the form of a diagram how strengths of SG and SD vary over time. The strengths of SG and SD are represented on the *y*-axis, with time on the *x*-axis. In the semantic profile, SG and SD are typically portrayed as inversely related, though this may not always apply or be analytically appropriate. In such cases, either drawing separate profiles or representing SG and SD on a *semantic plane*, allowing SG and SD to vary independent of each other (see Maton 2014; Blackie 2014, for a Chemistry example). The *semantic profile* can be used to map practices as they unfold in time, whether in a student task (e.g. an essay or problem task), a single classroom episode, part of a lesson, a series of lessons, an entire course or even a whole curriculum. Figure 11.1 shows three different semantic profiles: if these corresponded to three different lessons, then A1 would represent a lesson in which the teaching remained at the level of general principles, representing weaker semantic gravity and stronger semantic density (SG–, SD+); A2 would represent a lesson that remained at the level of specific examples, representing stronger semantic gravity and weaker semantic density (SG+, SD–); B would indicate a lesson where there was shifting in semantic gravity (context-dependence) and semantic density (complexity) through unpacking and repacking of representations. Profile B is said to have a greater ‘semantic range’ than either A1 or A2.

Variations in strengthening and weakening of semantic gravity and semantic density, Maton (2013) argues, is one way that meaningful learning is enabled. Many teachers of science go from the level of a general principle down into specific examples but never connect the examples back to the

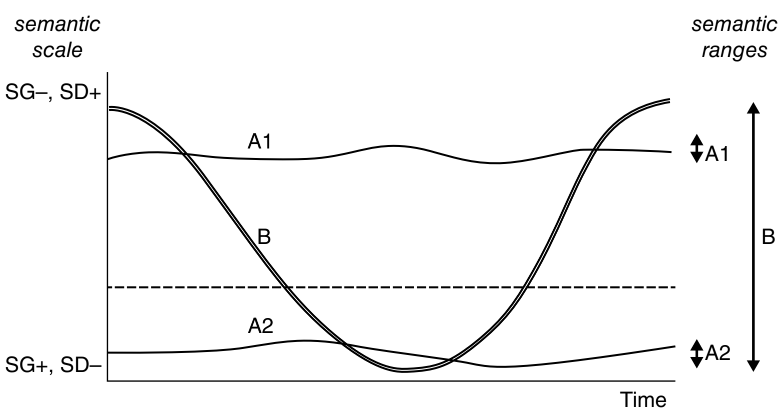

Figure 11.1 Illustrative profiles and semantic ranges (Maton 2013: 13).

underlying principle. Maton terms this a 'down escalator' profile because the teacher repeatedly 'unpacks' and simplifies technical concepts and relates these to specific examples, yet never models the process of shifting upward, through condensing meaning into technical terms or relating specific examples to the general principles (Maton 2013: 17). In this study, the method of semantic profiling is used to characterize the teaching practices in Physics and Mathematics courses.

Concepts from Specialization for thinking about transition to second year

In analyzing the form taken by knowledge in various disciplines, Bernstein (1996) introduced the concept of 'knowledge structure' and distinguished between 'hierarchical' and 'horizontal' knowledge structures. STEM disciplines (such as Physics, Chemistry, Biology) are typically characterized as 'hierarchical knowledge structures,' each being 'an explicit, coherent, systematically principled and hierarchical organization of knowledge' (Bernstein 1996: 172). Horizontal knowledge structures, on the other hand, are those which consist of 'a series of specialized languages, each with its own specialized modes of interrogation and specialized criteria' (Bernstein 1996: 172). Bernstein classifies Mathematics as a horizontal knowledge structure since 'it consists of a set of discrete languages for particular problems' (Bernstein 2000: 165); As Wolff elaborates, the 'languages' of Mathematics (for example, geometry, calculus, trigonometry, algebra) each have their own principles and procedures. They 'need to be acquired independently, and do not necessarily relate to each other or integrate concepts across the languages' (Wolff 2015: 39). Mathematics possesses what Bernstein terms a 'strong grammar,' meaning that its languages 'have an explicit conceptual syntax' (Bernstein 2000: 163). This is in contrast to horizontal knowledge structures with 'weak grammar' (for example, disciplines within the arts and humanities).

The Specialization dimension of LCT, with its concept of 'knowledge-knower structures,' usefully expands on Bernstein's conceptualization of knowledge structures by asserting that each knowledge structure also has an expectation, whether explicit or tacit, of a certain kind of ideal knower (Maton 2014). Specialization is based on the assumption that every social/educational practice is oriented towards something (knowledge) and by someone (knower). For each practice, it is necessary to identify '*what* can be legitimately described as knowledge (epistemic relations); and *who* can claim to be a legitimate knower (social relations)' (Maton 2014: 29). Epistemic relations (ER) and social relations (SR) in any practice can be stronger (+) or weaker (–), and can be represented on the *specialization plane*, as shown in Figure 11.2. By examining the epistemic relations and social relations of a particular practice, its position on the plane can be seen to fall into one of four quadrants – described as *knowledge codes*, *knower codes*, *élite codes* and *relativist codes*.

STEM disciplines are typically characterized as being characterized by stronger epistemic relations (ER+) since the scientific knowledge that the

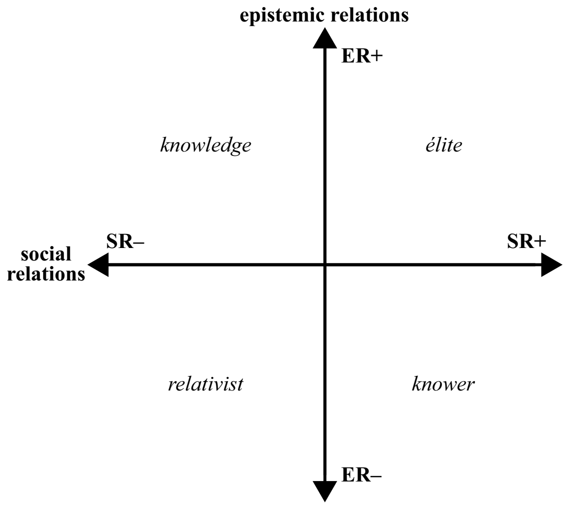

Figure 11.2 The specialization plane (Maton 2014: 30).

scientist possesses is emphasized and the attributes or dispositions of the scientist (or knower) are downplayed, representing weaker social relations (SR–): a *knowledge* code. Typically, Mathematics is typically characterized as a knowledge code. In contrast, in (for example) some humanities disciplines, specialized knowledge may be downplayed (ER–) and attributes of knowers may be emphasized (SR+): a *knower* code. Music as a high school subject is considered an *élite* code (Lamont and Maton 2008) since musical knowledge is valued (ER+), as well as having a musical 'feel' or disposition (SR+).

The characterization of Mathematics as a knowledge code (where dispositions of knowers are downplayed) is in contrast to the popular belief in that 'innate ability' matters in Mathematics learning. Contemporary Mathematics education research (e.g. Boaler 2016) notes the prevalence of the belief held by schoolchildren, their parents and teachers that 'some people are born with a "math brain" and some are not, and that high achievement is only available to some students.' This belief in 'innate ability' suggests relatively strong social relations and therefore suggests that Mathematics is often perceived as an élite code. This belief in 'innate ability' is also linked to the widespread phenomenon of 'Mathematics anxiety,' which is defined as anxiety about one's ability to do Mathematics. Mathematics anxiety correlates negatively with confidence and motivation (Ma 1999; Ashcraft 2002). This perception of the 'innateness' of Mathematics ability can also be traced to historical accounts of the development of Mathematics as a discipline. De Freitas and Sinclair (2014) note how the Cartesian mind-body divide is still dominant in Mathematics. They argue that this belief – that 'intuition' and 'innate mental talent' are key for success in Mathematics – can be alienating and play a gate-keeping role for the discipline.

In summary, contemporary research on Mathematics education as well as historical accounts of the development of Mathematics as a discipline suggests that a perception of 'innate ability' dominates, positioning these perceptions of Mathematics within an élite code on the Specialization plane. The implications of this is that Mathematics education needs to explicitly challenge these perceptions of 'innateness' – with not just a focus on the acquisition Mathematics knowledge, but also on developing the knower dispositions for the discipline (see, for example, Boaler (2016) on developing students' mathematical mindsets).

In the context of undergraduate science, echoing Maton's emphasis that 'there are always knowledges and always knowers' (2014: 96), Ellery (2018, 2019) has challenged the notion that the emphasis on specialized knowledge should eclipse issues about knowers dimensions. Ellery distinguishes between *production-context* knowers (as a scientist) and *learning-context* knowers (as a science learner). Production-context knowers need to value the epistemic norms and values of science, including rigour, curiosity, objectivity, working accurately, thinking analytically and critically (Ellery 2018: 31). Learning-context knowers need to develop knower attributes appropriate for learning university science. These include dispositions such as working independently, reflecting on one's learning (being metacognitive) and adopting appropriate approaches to learning (Ellery 2018); in other words, focusing on deep approaches (developing conceptual understanding) rather than surface approaches (focusing on rote learning) (Marton and Säljö 1976).

Ellery argues that in many traditionally content-dominated STEM courses (with a strong knowledge code), there is not enough explicit focus on developing knower dispositions, values and ways of thinking important for success in the discipline: 'to become effective science learners, students need to acquire not only certain practices and knowledge (representing weaker epistemic relations) but also certain knower dispositions (representing stronger social relations)' (Ellery 2019: 231). Similarly, Mtombeni (2018) argues that the lack of focus on social relations in a first-year Chemistry curriculum limits the development of students' knower dispositions.

An LCT analysis of the transition to second year

In this section, we draw on concepts from the LCT dimensions of Semantics and Specialization to develop an understanding of the hurdles students face in making the transition to second year. Using the concepts of semantic gravity and semantic density, we present semantic profiles of some representative Physics and Mathematics lessons to highlight differences and discontinuities in teaching practices between first-year and second-year courses. We also draw on the Specialization concepts of knowledge-knower structures and specialization codes to illuminate some of the difficulties students face in succeeding in their second-year studies. Data for this section is drawn from a previous study (Conana *et al.* 2019), which constructed semantic profiles of lecture sequences in first-year ECP Physics and second-year Physics and

Mathematics and interviewed second-year students about their experiences in transition to second year.

Semantics analysis

In applying the concepts of semantic gravity and semantic density to the context of undergraduate Physics, we used what in LCT is termed a 'translation device' (Maton and Chen 2016) which helped to show how concepts are realized in the empirical data of the study. The translation device draws on the work of Lindstrøm (2012) and Georgiou (2014), who have presented ways of coding the relative strengths of semantic gravity in the context of Physics lectures and students' responses to Physics tasks. They use the label *abstract* to refer to statements of general principles or laws; *concrete* refers to a description of specific examples; intermediate (or linking) refers to instances where general principles and specific examples are linked. Table 11.1 presents the translation device for semantic gravity and semantic density used in this study to characterize pedagogic practices.

In constructing semantic profiles of lessons, data was drawn from classroom observation notes and video recordings of lectures. From this data, semantic profiles were constructed to map shifts in semantic gravity and semantic density during lessons, as lecturers moved between abstract principles and specific examples, as well as the ways in which representations were unpacked or condensed during each lecture. The relative strengths of SG and SD were characterized as concrete, linking or abstract. At the concrete level, the lecturer would be referring to specific examples (SG+) and representations would be unpacked, often in the form of a verbal representation (SD–). At the abstract level, the lecturer would be using new concepts or general principles (SG–), mostly represented in semantically denser modes (graphical, diagrammatic, mathematical). The linking level is characterized by the lecturer building on familiar concepts or principles in a linking way; in doing so, dense representations were being explicitly unpacked or repacked into their constituent parts or meaning. For details of the data reduction and analysis process, and the translation device used, see Conana *et al.* (2019).

Through mapping shifts in semantic gravity and semantic density, semantic profiles were constructed for several lessons. Here, we present three

Table 11.1 Translation device for various levels of Semantics

	Realizations of semantic gravity	*Category*	*Realizations of semantic density*	
SG– ↑	New general principles	Abstract A`	Representations (or nominalizations)	SD+ ↑
	Familiar principles used in a linking way	Linking (Intermediate) L	Unpacking or repacking representations	
↓ SG+	Specific examples	Concrete C	Linking representations to specific examples	↓ SD–

semantic profiles: one for an ECP Physics lesson (Figure 11.3), one for a second-year Physics lesson (Figure 11.4) and one for a second-year Mathematics lesson (Figure 11.5). On the semantic profiles, coding (in the form of line thickness) is used to indicate the different forms of interaction in lectures (with a thin line indicating where only the lecturer is talking and a thick line indicating lecturer-student interactions).

A more detailed analysis of these semantic profiles is given in Conana *et al.* (2019). The comparison of the first year and second year semantic profiles, together with data from student interviews, highlighted several key differences or discontinuities in teaching practices:

Firstly, the *semantic range* in the lessons diminishes with the transition to second year. As evident in Figure 11.3, the first year ECP teaching spans a

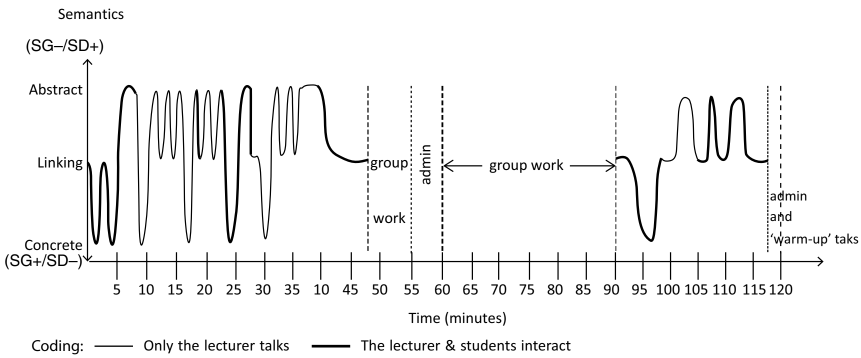

Figure 11.3 Semantic profile of a first-year ECP physics lesson.

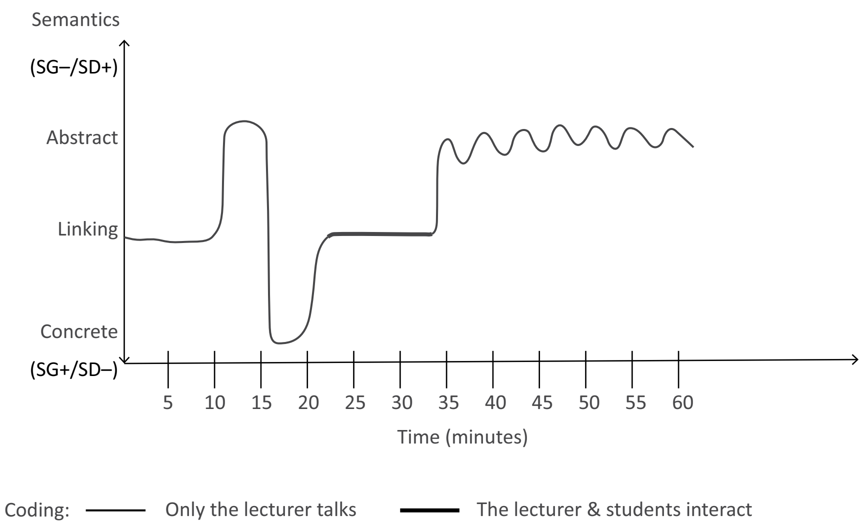

Figure 11.4 Semantic profile of a second-year physics lesson.

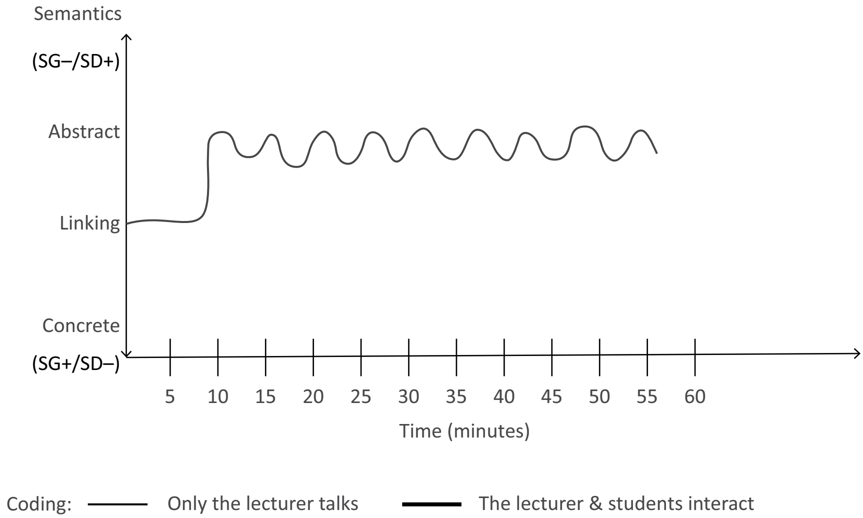

Figure 11.5 Semantic profile of a second-year mathematics lesson.

large semantic range (spanning abstract and concrete). By contrast, the semantic range of the second-year Physics and Mathematics course is narrower, predominantly at the abstract level, which is to be expected in these more mathematically advanced courses. Some students describe how the increased abstraction led to a decrease in motivation for their studies; for example: 'I've lost my motivation this year – it's just theory,' and 'There's something missing in terms of what is happening this year – I've lost that 'Oomph' in Maths.'

Secondly, *interactive engagement* was a key aspect in the first-year ECP teaching that was less common in much of the second-year teaching. The semantic profile in Figure 11.3 shows that student engagement was a key feature of the lecture sequence: the line thickness coding on the semantic profile indicates the many times during the lecture when there was student engagement. The faster pace of the second-year courses precluded much interaction with lecturers. Students noted how they missed this engagement and would have welcomed more structured group work in their second-year classes; for example: 'Our lecturers are not interacting with us….They are so fast, they are just running with the notes' and 'It would be much better if we could work in groups, like in first year, because you can work with someone else than working on your own. It was more effective.'

Thirdly, the range of *representational modes* used in the second year narrowed. While ECP Physics teaching explicitly incorporated a range of representational modes (gestures, diagrams, graphs, mathematical equations), in the second-year courses, mathematical representations inevitably became more prevalent. This is to be expected in senior Physics and Mathematics courses. However, what the second-year Mathematics students noted was that representations with strong semantic density were often taken for granted and not explicitly unpacked in the teaching; for example: 'The problem is, now everything is abstract. We have to picture these problems. I struggle to visualize them. I tried to, but you *have to capture all these concepts visually*,' and 'Our lecturers teach us how to draw graphs but never teach us *how to view them*.... I have a lot of sketches in my notebook that I still don't understand.'

In summary, the Semantics analysis highlighted the discontinuities in teaching practice from first year to second year. These included: a curtailed semantic range concentrated more at the abstract level, less interactive engagement, a narrower range of representations used and less explicit unpacking of these representations in second year.

Specialization analysis

Data from student interviews was analyzed with the Specialization concept of 'knowledge-knower structures,' which highlights the importance not just to focus on disciplinary knowledge but also 'knower dispositions.' Perceptions of Mathematics as an élite code were evident in interviews with the second-year Mathematics students, where the notion of 'innate talent' was implicit. One student commented that most of the Mathematics postgraduate students seemed to come from outside of South Africa and questioned whether local students were perhaps not strong enough for postgraduate Mathematics studies.[1]

Furthermore, student interviews suggested that some of the learning-context knower dispositions that had begun to be developed in the ECP were no longer explicitly addressed in the second year Mathematics. These included encouraging students to work independently, to work collaboratively on whiteboards and discuss Mathematics. Students noted that they missed the opportunity for structured group work; for example: 'We are not interactively doing the work in class, most of us we are doing the work at home alone. I feel like we should do group work.'

Ellery notes that 'while disciplinary knowledge tends to form the main focus of science courses, becoming and being an independent learner is usually expected of students but is seldom explicitly articulated nor specifically supported, and therefore remains part of the "hidden curriculum"' (Ellery 2019: 234). She argues that knower dispositions, such as becoming an autonomous learner, needs to be explicitly modelled and scaffolded.

Students' reflections on their experience of second year suggested that they found the abrupt lack of this modelling and scaffolding of their independent learning difficult. It was assumed that students would work through notes and exercises at home, but this was not made explicit nor guided; for example:

> When you advance to second year maths you just get a shock. This year, in second year maths, the lecturer just reads the notes and explains a few concepts and just – you need to do it all at home. There's no time [as in

> first year] that you have to work on something for weeks, it's just about what you are doing at home.
>
> I feel like there's lots of gaps this year. You have to constantly go back, which is, you have to do the stuff everyday in order to get it. But the more you go back, the more you fall behind and the more you create more gaps for yourself. Unless you can work very fast, your time will fall short. This year, it is all about how you use your time. In first year, it wasn't like this. When we started with second year, it was like 'Boom!' They were all throwing things on us, it is so overwhelming.

In summary, the Specialization analysis highlighted the prevalence of an élite code perception among students, as well as a lack of modelling and scaffolding of learning-context knower dispositions in the second year Mathematics.

Rethinking teaching practices based on LCT analysis

The LCT tools had provided useful insights into the challenges students face in the transition to second year. The Semantics findings suggested that attentiveness to particular aspects of the teaching (semantic range, interactive engagement and the use of multiple representational modes) would be likely to support students in accessing the disciplinary knowledge and in navigating the 'epistemic transition' to second year. The Specialization findings suggested that attentiveness to the knower dispositions needed for STEM studies would also be important.

The next step was to use this LCT analysis to rethink and redesign aspects of the second-year teaching and curriculum. The high failure rate in second-year Mathematics was a grave concern, and so the first author (the faculty's teaching and learning specialist) presented the research findings to the Mathematics Department. This generated much discussion among the second-year lecturers and a willingness to work alongside the teaching and learning specialist in rethinking the second-year courses. LCT provided a useful conceptual framework for this collaboration; as Clarence has noted in her work with academic staff, the LCT tools assisted 'both academic development practitioners and disciplinary educators, working collaboratively, to analyse and change pedagogical practice in higher education' (2016: 126). This model of collaboration between educational specialist/academic literacy practitioner and disciplinary lecturers is described by Jacobs (2007), who argues that disciplinary lecturers are so immersed in their respective disciplines that the representations and discourse features of their discipline tends to be tacit and often taken for granted and that they may therefore find it difficult to make these discipline representations explicit to their students (see also, Marshall *et al.* 2011, for an example of this collaborative model in the context of Physics). In the section that follows, we discuss how the findings from the LCT analysis were used to rethink teaching practices.

Changes introduced on the basis of Semantics analysis

The purpose of classroom sessions was altered – instead of class time being used for the transmission of course material, students were expected to come to class prepared so that time could be spent tackling Mathematics tasks in class. This was achieved by replacing the traditional lecture format with an interactive workshop format, encouraging *student engagement*, discussion and 'talking Mathematics.' As one student who had failed the course in the previous year commented: 'Last year we would just sit in rows and listen; now we can interact and talk Mathematics to each other.'

There was a deliberate focus on widening the *semantic range* in classroom sessions through referring to specific examples whenever feasible. In Mathematics, the process of moving from specific examples to the general principles is termed 'abstraction,' which many students find challenging. Wiggins (2018) argues that Mathematics lecturers need to emphasize that Mathematics has its roots in the study of real-world problems and to demonstrate abstract concepts through specific examples whenever feasible.

Mastering disciplinary representations takes place over an extended period of time, beyond first year. Yet, as Fredlund *et al.* (2012) note, lecturers are often so familiar with disciplinary representations that are oblivious to the 'learning hurdles' involved in interpreting the intended meaning of these representations (also see, Conana *et al.* 2016, 2020). In response to the students' and researchers' observations that representations were often taken for granted in the second-year Mathematics course, there was also a more explicit focus on exploring and unpacking a *range of representations*. Wood *et al.* (2007) argue that a key purpose of undergraduate Mathematics teaching is 'to assist students to make links between various representations of mathematical concepts' (p. 12), including oral and written language, mathematical notations and visual diagrams. They argue that these links between representations 'form the basis for deep learning and fluency in working with mathematical ideas' (ibid.:12).

Changes introduced on the basis of Specialization analysis

The Specialization analysis emphasized that, while Mathematics knowledge is central (relatively strong epistemic relations), more time is needed in the curriculum to address knower dispositions (strengthening social relations). As Ellery (2019) argues, in many traditionally content-dominated STEM courses (with a strong knowledge code), there is not enough explicit focus on developing the knower dispositions, values and ways of thinking important for success in the discipline.

Drawing on Ellery's work, the interventions were designed to develop students' knower dispositions. One key aspect of the interventions was to challenge the 'innateness' belief that situates Mathematics as an élite code in students' eyes. Through developing students' dispositions, such as confidence, autonomous learning, deep approaches to learning and enhanced metacognitive capabilities, the notion was emphasized that success in Mathematics relies on 'attitude, not aptitude.'

Before the start of the second year, a weeklong 'boot camp' was held for all second-year Mathematics students. This was explicitly geared towards supporting students in the transition to second year: sessions focused on overtly articulating the sorts of knower dispositions needed for second year Mathematics and these were modelled during the weeklong intervention.

Sessions on the nature of mathematical thinking developed the *production-context* knower dispositions relevant for Mathematics, the epistemic norms and ways of thinking in Mathematics. These included sessions on logic, and the role of proof in Mathematics. Hodds *et al.* (2014) recommend an intervention that focuses on logical relationships and introduced a pedagogical technique called '*self-explanation training*' to help students with the comprehension of proofs. Worksheets were developed that systematically deconstruct the theorem, followed by a rigorous set of step-by-step guidelines through the body of the proof that helps a student to understand technical terms used and to develop their cognitive capacity to handle the details of deductive arguments.

Many students initially voiced anxiety at the prospect of dealing with the advanced Mathematics of second year; the boot camp provided a broad, conceptual introduction to the second-year mathematical courses (Advanced Calculus and Linear Algebra), emphasizing the real-world origins of these mathematical fields and how students' high school and first-year Mathematics knowledge formed the foundation for these more advanced-level courses. In addition, the role of Mathematics as the language of the sciences was foregrounded (with sessions on Mathematics for Physics, Statistics, Computer Science and Chemistry by lecturers from these disciplines).

Other sessions addressed the *learning-context* knower dispositions appropriate for learning Mathematics. These included students' dispositions such as autonomous learning, adopting deep approaches to learning and developing metacognitive capabilities. Boot camp activities developed students' metacognition, with many opportunities to reflect on their learning and identify challenges. Mathematics education research shows the value of this sort of explicit focus on students' approaches to learning and their conceptions of Mathematics: Wood *et al.* (2012) identified three levels of conceptions of Mathematics, ranging from fragmented conceptions of Mathematics as a collection of components and techniques (level 1), Mathematics as a focus on models and abstract structures (level 2) and Mathematics as tools for understanding the world (level 3). Studies show that fragmented conceptions of Mathematics (level 1) are linked to surface approaches to learning and poor-quality learning outcomes, whereas the more cohesive conceptions of Mathematics (levels 2 and 3) are linked to deep approaches to learning and better learning outcomes (Crawford *et al.* 1994, 1998).

Besides the initial boot camp, the teaching approach of the second-year Mathematics courses was adapted in response to the research findings. As noted above, the traditional lecture format was transformed into a workshop format. Students' capacity to *work independently* was supported and developed through assigning class preparation worksheet tasks so that more time was freed up during class for in-class activities and discussion of the challenges the students encountered in the tasks.

Students' *metacognition* was developed through activities that encouraged them to reflect on their approaches to learning and identify problem areas they were experiencing. In class, students worked in groups on tasks and were encouraged to discuss their thinking, and compare solutions. Students were encouraged to present their struggles to the whole class, and peers would then suggest strategies and different approaches to solving the problems.

The development of these knower dispositions was enabled by the sense of a classroom community, which gave students the space and confidence to 'speak' Mathematics and to feel part of a learning community (see Engstrom and Tinto 2008, on the impact of learner communities on student retention in higher education). This minimized the Mathematics anxiety many students were laden with. In addition, physical space was created in one of the Faculty buildings for students to meet informally and discuss Mathematics – this space had movable tables and chairs, and plenty of whiteboards for working on tasks together. During some classes, postgraduate students were invited to do short twenty-minute presentations; these students were role models for second-year students, helping them to envisage themselves as becoming mathematicians.

Impact of the intervention on student learning

Overall, the Mathematics lecturers reported an increased confidence in students and improved attitude towards Mathematics learning. The opportunity to 'talk Mathematics' built their confidence and developed their sense of themselves as 'Mathematics students.' Their sense of agency in relation to their Mathematics learning developed; as their metacognitive approach developed, they became less focused on getting the right answer and more focused on the mathematical process. This was evident in the student exchanges on an informal 'WhatsApp group' the students had created: the emphasis was not on sharing solutions to problems, but rather on providing feedback to each other on approaches to problems. Examples of peer comments were: 'Did you think about …'? 'What am I missing here?'; 'No-one post a solution please – I want to figure it out myself.'

As students' sense of identity as Mathematics students deepened, there were unexpected developments: the students formed a Mathematics Club (which arranged lunchtime seminars and events), and a Mathematics Hub (a campus residence-based Mathematics Club). Students' confidence to speak about Mathematics also led to the establishment of an outreach project in local high schools. More students wanted to take part in the South African Tertiary Mathematics Olympiad, indicating that the science knower disposition of curiosity (see Ellery 2018) had been fostered in these students, as they enjoyed applying their creativity and critical thinking skills, and exploring concepts beyond the second-year curriculum.

The students also began to reflect more on the relationship between Mathematics and their other second-year science courses, and lecturers in these other courses noted improved success in these courses. As much as motivation, attitude and confidence matter, the main currency of undergraduate education is assessment results, and here the impact of the intervention was significant: the pass-rate in the second-year Mathematics courses increased significantly, from about 30% to about 80%.

Another interesting development was that the positive 'turnaround' in second-year Mathematics had a wider impact in the Mathematics Department as a whole. More senior postgraduate tutors were now willing to tutor second-year courses: in the past, they had found tutoring demoralizing, but now they were keen to work with these motivated students and keen to motivate them further. Similarly, the newly motivated second-year students became keen to tutor the first-year students, and as a result, the first-year Mathematics pass-rate also increased. In the year subsequent to the first implementation of this intervention, the enrolment in third-year Mathematics more than doubled, from 15 to about 40 students.

Concluding remarks

This research on the transition from first to second year in higher education addresses the paucity of research in this area. We note that in South Africa, as elsewhere, most of the research focuses on the transition from school to higher education and neglects 'epistemic transitions' (CHE 2013) later in the trajectory of undergraduate students.

Concepts from Semantics and Specialization provided useful insights into the challenges students face in the transition to second year. The Semantics analysis suggested that attentiveness to particular aspects of the teaching (greater semantic range, more interactive engagement, the use of multiple representations and more explicit unpacking of these) would be likely to support students in accessing the disciplinary knowledge and in navigating the 'epistemic transition' to second year. The Specialization analysis highlighted the way that Mathematics operates as an élite code for many university Mathematics students; the findings suggested that, while a focus on knowledge tends to dominate undergraduate Mathematics teaching, attentiveness to the *production-context* knower dispositions and *learning-context* knower dispositions (Ellery 2018) needed for success in Mathematics studies would also be important. These LCT research findings were then used to frame an educational intervention in second-year Mathematics. This intervention was found to lead to significant changes in students' attitudes towards Mathematics learning, as well as in their learning outcomes. Although the focus of our analysis in this chapter was second-year Mathematics, these findings would likely be applicable to a range of STEM disciplines. The Semantics and Specialization tools are valuable for teasing out ways in which the semantic features and the knowledge-knower structures of a discipline might be made more accessible to students.

Note

1 Under Apartheid in South Africa, deliberate education policy restricted access to quality Mathematics education for black learners.

References

Ashcraft, M. H. (2002) 'Math anxiety: Personal, educational, and cognitive consequences,' *Current Directions in Psychological Science*, 11(5): 181–185.

Bernstein, B. (1996) *Pedagogy, symbolic control and identity: Theory, research, critique*, Taylor and Francis.

Bernstein, B. (2000) *Pedagogy, symbolic control and identity: Theory, research, critique*, Revised edition. Rowman and Littlefield.

Bing, T.J. and Redish, E.F. (2009) 'Analyzing problem solving using math in physics: Epistemological framing via warrants,' *Physical Review Special Topics – Physics Education*, 5: 020108.

Blackie, M. (2014) 'Creating semantic waves: Using Legitimation Code Theory as a tool to aid the teaching of chemistry,' *Chemistry Education Research and Practice*, 15: 462–469.

Boaler, J. (2016) *Mathematical mindsets: Unleashing students' potential through creative math, Inspiring Messages and Innovative Teaching*, John Wiley and Sons.

Bourdieu, P. (1994) *In other words*, Polity Press.

Clarence, S. (2016) 'Exploring the nature of disciplinary teaching and learning using Legitimation Code Theory semantics,' *Teaching in Higher Education*, 2(2): 123–137.

Conana, H., Marshall, D. and Case, J. (2016) 'Exploring pedagogical possibilities for transformative approaches to academic literacies in undergraduate physics,' *Critical Studies in Teaching and Learning*, 4(2): 28–44.

Conana, H., Marshall, D. and Solomons, D. (2019) 'Legitimation Code Theory as a theoretical lens to think about transition,' *Alternation*, 26(2): 183–212.

Conana, H., Marshall, D. and Case, J. (2020) 'A semantics analysis of first year physics teaching: Developing students' use of representations in problem-solving,' in C. Winberg, S. McKenna and K. Wilmot (eds) *Building knowledge in higher education: New directions in teaching and learning*, Routledge.

Council on Higher Education (CHE) (2013) 'A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure.' Report of the Task Team on Undergraduate Curriculum Structure. Retrieved from: http://www.che.ac.za/media_and_publications/research/proposalundergraduate-curriculum-reform-south-africa-case-flexible.

Crawford, K., Gordon, S., Nicholas, J. and Prosser, M. (1994) 'Conceptions of mathematics and how it is learned: The perspectives of students entering university,' *Learning and Instruction*, 4(4): 331–345.

Crawford, K., Gordon, S., Nicholas, J. and Prosser, M. (1998) 'University mathematics students' conceptions of mathematics,' *Studies in Higher Education*, 23(1): 87.

De Freitas, E. and Sinclair, N. (2014) *Mathematics and the body: Material entanglements in the classroom*, Cambridge University Press.

Ellery, K. (2018) 'Legitimation of knowers for access in science,' *Journal of Education*, 71: 24–38.

Ellery, K. (2019) 'Congruence in knowledge and knower codes: The challenge of enabling learner autonomy in a science foundation course,' *Alternation*, 26(2): 213–239.

Engstrom, C. and Tinto, V. (2008) 'Access without support is not opportunity,' *Change: The Magazine of Higher Learning*, 40(1): 46–50.

Fredlund, T., Airey, J. and Linder, C. (2012) 'Exploring the role of physics representations: An illustrative example from students sharing knowledge about refraction,' *European Journal of Physics*, 33: 657–666.

Georgiou, H. (2014) 'Putting physics knowledge in the hot seat: The semantics of student understandings of thermodynamics,' in K. Maton, S. Hood and S. Shay (eds) *Knowledge-building*, Routledge.

Hodds, M., Alcock, L. and Inglis, M. (2014) 'Self-explanation training improves proof comprehension,' *Journal for Research in Mathematics Education*, 45(1): 62–101.

Hunter, M.S., Tobolowsky, B.F., Gardner, J.N., Evenbeck, S.E., Pattengale, J.A., Schaller M.A. and Schreiner, L. (eds) (2010) *Helping sophomores success: Understanding and improving the second year experience*, Jossey-Bass.

Jacobs, C. (2007) 'Towards a critical understanding of the teaching of discipline-specific academic literacies: Making the tacit explicit,' *Journal of Education*, 41(1): 59–82.

Lamont, A. and Maton, K. (2008) 'Choosing music: Exploratory studies into the low uptake of music GCSE,' *British Journal of Music Education*, 25(3): 267–282.

Lindstrøm, C. (2012) 'Cumulative knowledge-building in a hierarchically knowledge structured discipline: Teaching university physics to novices,' Paper presented at the *Seventh International Basil Bernstein Symposium*, Aix-en Provence, France.

Ma, X. (1999) 'A meta-analysis of the relationship between anxiety towards Mathematics and achievement in mathematics,' *Journal for Research in Mathematics Education*, 30(5): 520–541.

Marshall, D., Conana, H., Maclons, R., Herbert. M. and Volkwyn, T. (2011) 'Learning as accessing a disciplinary discourse: Integrating academic literacy into introductory physics through collaboration partnership,' *Across the Disciplines*, 8(3): 1–9.

Marton, F. and Säljö, R. (1976) 'On qualitative differences in learning. 1 – outcome and process,' *British Journal of Educational Psychology*, 46: 4–11.

Maton, K. (2009) 'Cumulative and segmented learning: Exploring the role of curriculum structures in knowledge-building,' *British Journal of Sociology of Education*, 30(1): 43–57.

Maton, K. (2013) 'Making semantic waves: A key to cumulative knowledge-building,' *Linguistics and Education*, 24(1): 8–22.

Maton, K. (2014) *Knowledge and Knowers: Towards a Realist Sociology of Education*, Routledge.

Maton, K. (2020) 'Semantic waves: Context, complexity and academic discourse,' in Martin, J. R., Maton, K. and Doran, Y. J. (eds) *Accessing Academic Discourse: Systemic functional linguistics and Legitimation Code Theory,* Routledge, 59–85.

Maton, K. and Chen, R. T-H. (2016) 'LCT in qualitative research: Creating a translation device for studying constructivist pedagogy,' in K. Maton, S. Hood and S.

Shay (eds) *Knowledge-building: Educational studies in Legitimation Code Theory*, Routledge, 27–48.

Mtombeni, T. (2018) 'Knowledge practices and student access and success in General Chemistry at a Large South African University,' Unpublished PhD thesis, Rhodes University.

Wiggins, H.Z. (2018) 'Mathematics: Forget simplicity, the abstract is beautiful - and important.' *The Conversation*. https://theconversation.com/mathematics-forget-simplicity-the-abstract-is-beautiful-and-important-91757. (Accessed 27 May 2021).

Wolff, K. (2015) 'Negotiating disciplinary boundaries in engineering problem-solving practice,' Unpublished PhD thesis, University of Cape Town.

Wood, L.N., Joyce, S., Petocz, P. and Rodd, M. (2007) 'Learning in lectures: Multiple representations,' *International Journal of Mathematical Education in Science and Technology*, 38(7): 907–915.

Wood, L., Petocz, P. and Reid, A. (2012) *Becoming a mathematician*, Springer.

Yorke, M. (2015) 'Why study the second year?' in C. Milsom, M. Stewart, M. Yorke and E. Zaitseva, (eds) *Stepping up to the second year at university: Academic, psychological and social dimensions*, Routledge.