1 Enacting Legitimation Code Theory in science education

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Introduction

The purpose of science education is not only to produce a new generation of scientists but also to offer young people understanding about the vast explanatory power that science has to offer to a world faced with complex challenges. Debates on how to handle existential threats such as global warming and diseases like COVID-19 are good examples of such problems. Osborne and Dillon (2008) argue that science education 'should be to educate students both about the major explanations of the material world that science offers and about the way science works.' Moreover, scientific understanding and reasoning are desired attributes for the future citizen in many countries of the world. Wide-ranging studies have shown that this aspiration will require dedicated investments in skilled science educators that continuously develop their own knowledge and teaching practice, the development of genuinely engaging curricula, as well as assessment protocols and structures that will meet the desired outcomes and goals. Currently, we are not achieving this ideal. Many European countries, for example, have witnessed a decline in the number of students who enrol for degrees in science (Osborne and Dillon 2008). Moreover, science education continues to represent a substantial hurdle for both lecturers and students around the globe. Students find science courses difficult to master, and lecturers find science courses challenging to teach, although the nature of that challenge varies from subject to subject (Sithole *et al.* 2017). Nonetheless, science education has tended to focus on the mastery of particular scientific concepts rather than on the induction of the student to the knowledge field as a whole.

Many academic scientists are interested in developing and improving their own pedagogy but may struggle to find a 'way into' engaging with the scholarship of teaching and learning (Adendorff 2011). Conducting science education research is an even bigger challenge. The stumbling block for many academics making this transition is the apparent lack of clarity on the links between methods and theoretical frameworks (Adendorff 2011). Whilst some educationalists have attributed the lack of impact of their work on the practices of many science educators to an arrogant dismissal of education as unscientific, this is far too simplistic and one-sided. Differences of

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terminology, methodology, style and even epistemology can make research into science education appear daunting and alien to university-based scientists. Moreover, some approaches in science education research are less than convincing with the use of vague terminology, loose logic and minimal empirical evidence. There is thus a need for an approach that is clear, explicit, evidential and rigorous, to help engage scientists with scholarship that can enhance their pedagogic practices and enable science education research. This book brings together a rich collection of studies in science education that uses a common framework, Legitimation Code Theory, to attend to these concerns.

Legitimation Code Theory (LCT) provides a welcome entry point into a scholarly approach to science pedagogy, as well as rigorous science education research. Moreover, we have found that academic scientists experience LCT as more 'science-like' and therefore 'less foreign,' relative to other education research frameworks. LCT offers a suite of tools which can be used for a wide range of purposes (which is explained later in this chapter). For example, it may be used to analyze conceptual gain, or to evaluate the ways in which knowledge and social relations interact in a particular situation or to interrogate the aims and purposes of different learning activities in a course. We can use the framework to examine from the ways in which scientific concepts are taught to the ways we structure science assessments (Rootman-le Grange and Blackie 2018, 2020; Steenkamp *et al.* 2019).

There is already a diversity of ways in which LCT has been enacted for evaluating and shaping science pedagogy and curricula, with the framework finding application in Biology (Mouton and Archer 2019; Mouton 2020), Chemistry (Blackie 2014) and Physics (Georgiou 2016), to name but a few. LCT comprises several 'dimensions' or sets of concepts, one of which is Semantics. The following three examples all make use of Semantics in different ways. Conana *et al.* (2016) analyzed the way in which language and concepts were used in an introductory Physics course. These authors showed that the lecturer almost exclusively used specialist language, which was troublesome for students to access. LCT holds that knowledge-building for epistemological access requires waves of movement between simpler, everyday language and the more specialist language of the subject (Maton 2009). Kelly-Laubscher and Luckett (2016) used Semantics to show that there is a vast disparity in complexity between high school and university Biology textbooks. This difference may be one of the reasons why students who achieved good marks in school struggled with the subject in their first year at university. Mouton and Archer (2019) and Mouton (2020) have since built on these findings in Biology to develop a pedagogy and learning activities to mitigate the articulation gap between school and first year in higher education. In all of these studies, LCT was used to reveal tacit problems and to shape teaching practice to overcome the problems. These are just some possibilities among many. LCT offers the possibility of a breadth of exploration at any level – from a single lecture or practical, to an entire degree programme.

Through the exploration of LCT, two further aspects of education have come into view: cumulative knowledge-building (Maton 2009) or extending existing ideas and integrative knowledge-building (Maton and Howard 2018) or productively bringing together different ideas. Science students often struggle to recognize particular scientific concepts in a different context, a key outcome of most science programmes. Cumulative knowledge-building is essential to ensure that a student will be able to use concepts and language beyond the scope of the particular course, such as the capacity to use science concepts of acids and bases taught in an introductory Chemistry course in a second-year Biochemistry course or in real-world problems pertaining to acid rain. Integrative knowledge-building is the integration of different kinds of knowledge – this is the foundation for lifelong learning and key to solving real-life, complex problems. For example, recognizing that developing new, healthier and cheaper or more sustainable food products draws from knowledge in Chemistry, Biochemistry and Microbiology. Similarly, understanding the mechanism of infection of a virus such as SARS-CoV-2, the cause of COVID-19, requires drawing knowledge from different disciplines.

The methodology of LCT also offers a significant advantage to academics who have been used to disciplinary STEM-based research. Feedback from various workshops on LCT suggests that academic scientists find that the integral use of Cartesian planes (described later in this chapter) offers a familiar visual framework which somehow makes LCT feel more 'science friendly.' The take up of LCT in the science community speaks for itself.[1] This emerging body of work shows how academics across scientific disciplines have used LCT in the analysis and shaping of their current teaching practice. To date, such efforts have been largely *ad hoc*. The vast majority of papers have come from a relatively small community of science educators who have stumbled across LCT and found it very useful, though the rapid growth of this community in recent years is reaching a critical mass of productivity. It is thus timely to gather a collection of these efforts to show something of the range of what the use of LCT can achieve within a scientific context.

In this chapter, we introduce the conceptual framework, LCT, to science educators. We look at each of the LCT dimensions that are used throughout this book – Specialization, Semantics and Autonomy. At the end of this chapter, we present a brief summary of the chapters that reach across the sciences and which embrace curriculum design, pedagogic practice and assessment.

Legitimation Code Theory

LCT is a realist framework, developed by Karl Maton (2014), which builds on the work of Basil Bernstein and Pierre Bourdieu, among others. It offers a multi-dimensional approach for exploring what it means to know and how one comes to know in different disciplines or knowledge practices (Winberg *et al.* 2020). The sociologists Bernstein and Bourdieu both witnessed the wave of massification of higher education, which shifted the demographic of the student body from a small, privileged élite to a large diverse group including more social classes. It soon became apparent that this greater access did not translate to success for all since not all students had the cultural and social capital required to engage meaningfully in higher education. This has been highlighted by Morrow's (2009) work on 'epistemological access' to the required knowledge. The work of Bernstein (2000), Bourdieu (1988) and Morrow (2009) aim to expose some of the impediments to entry into academia. LCT has a similar social justice agenda – making the 'rules of the game' explicit to all participants, potentially affording access to those who have not been culturally conditioned to see the dynamics in play (Maton 2014).

One of the ways in which LCT does this is by addressing the issue of *knowledge-blindness*, where knowledge is reduced to knowing (mental processes of understanding) whilst losing sight of the organizing principles at play in different knowledge practices (Maton, 2014: 3). With its focus on revealing these underlying logics, LCT allows us to show the ways in which coming to 'know' differ across different knowledge practices. LCT's set of tools can be enacted to explore knowledge, i.e. what counts as a legitimate claim, who is allowed to make such a claim, and how meaning is made by making explicit that which is often hidden or tacit and taken for granted. Its various concepts and dimensions offer a means to reveal different aspects of these 'rules of the game' in diverse practices.

Dimensions of LCT

Three of LCT's dimensions are well developed and in fairly wide usage: Specialization, Semantics and Autonomy. Specialization and Semantics are both thoroughly described in *Knowledge and Knowers* (Maton 2014) and in *Knowledge-Building* (Maton *et al.* 2016). Autonomy was not fully developed at that time, but an extensive overview of this dimension was presented in a paper written by Maton and Howard (2018). As mentioned earlier, these three dimensions allow exploration of different aspects of knowledge practices. Specialization is focused on how knowledge and knowers are legitimated in different knowledge practices. Semantics reveals how meaning is made. Autonomy explores the origin and purposes of various constituents of knowledge practices. Each LCT dimension is conceived as a combination of two organizing principles. These two organizing principles are independent of one another, each with the ability to vary from weaker to stronger, and can thus be plotted on a Cartesian plane with each of the principles represented by one of the axes. Practices can valorize one, both or neither of the organizing principles, leading to four overarching modalities for each dimension, which are called 'codes.'

Specialization

Specialization focuses on the basis for legitimacy in different practices, i.e. who can make a legitimate knowledge claim, as well as what would constitute a legitimate knowledge claim. This starts from the perspective that all knowledge claims are about something and made by someone. The organizing principles in the case of Specialization are *epistemic relations* (ER), between the knowledge practice and its objects, and *social relations* (SR), between the practice and its subjects. Fields with relatively strong epistemic relations (ER+) place emphasis on knowledge, skills and procedures whilst fields with relatively strong social relations (SR+) valorize dispositions, values and attributes of knowers (Maton 2014). The two relations can be plotted as the *specialization plane*, with four principle modalities or *specialization codes* as shown in Figure 1.1 (Maton *et al.* 2016). Knowledge practices are always underpinned by epistemic relations and social relations, but it is the degree to which each organizing principle is emphasized that determines the basis of achievement in a particular practice. As stated above, practices can emphasize one, both or neither of these relations as a basis for legitimacy whilst both relations can vary from stronger to weaker, allowing an infinite number of strengths or positions on the specialization plane (Figure 1.1).

The principal modalities or *specialization codes* are (Figure 1.1):

- *knowledge codes* (ER+, SR–) arise when we have stronger epistemic relations (ER+) coupled with weaker social relations (SR–), i.e. where practices emphasize the possession of specialized skills, knowledge or procedures as the basis for success whilst downplaying the attributes of the actor making the claim. In this code, what one knows is important, and one's dispositions may be gently overlooked. Legitimate participation in the natural sciences is often dominated by different variations of this code.
- *élite codes* (ER+, SR+) arise when stronger epistemic relations (ER+) are coupled with stronger social relations (SR+), i.e. where practices emphasize the possession of both specialized skills, knowledge or procedures and attributes of the actor making the claim. In this code, both what one knows and who you are provide the basis for legitimacy. Fields that are both technically demanding and require some kind of individual expression, such as professional classical music performance, may be dominated by this code.
- *knower codes* (ER–, SR+) arise when weaker epistemic relations (ER–) are coupled with stronger social relations (SR+), i.e. where practices emphasize the attributes of the actor making the claim and downplay the possession of specialized skills, knowledge or procedures as the basis for legitimacy. In this code, who one is, is important, not what one knows. Many practices in the humanities are dominated by this code, through notions of a cultivated gaze.
- *relativist codes* (ER–, SR–) arise when legitimacy is determined by neither one's specialist knowledge nor one's personal attributes. This is a sort of 'anything goes,' such as when brainstorming without limits on what is a permissible idea to add.

Knowledge of the dominant code in a practice can help us unpack the rules for legitimacy, or the basis for achievement, in that practice. Besides the

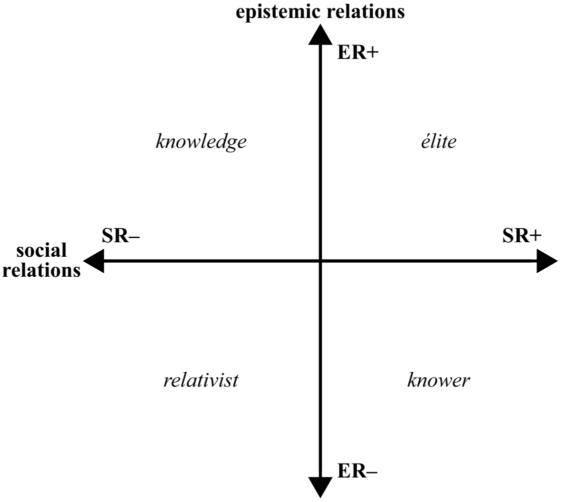

Figure 1.1 The specialization plane (Maton 2014: 30).

ability to change or shift over time, codes can also match, i.e. when two sets of practices use the same basis for success, or codes can clash. Code clashes occur when people or practices are characterized by different codes. Scientists who undertake education research for the first time often experience such a *code clash* when introduced to literature in teaching and learning that uses a knower code as its basis for claims. This might also be one reason why LCT, with its stronger epistemic relations, has found traction in many science environments.

Each of these organizing principles – epistemic relations and social relations – can be explored in more detail. 'Epistemic relations' can be broken down into 'what practices relate to and how they so relate' (Maton 2014: 174). These are *ontic relations* (OR) between knowledge practices and their objects of study, and *discursive relations* (DR) between knowledge practices and other knowledge practices (such as between different theories and methods). These relations can be plotted on the *epistemic plane* (see Figure 1.2), allowing us to distinguish four principal modalities or *insights*:

- *doctrinal insight* (OR–, DR+): what counts as legitimate objects of study is not tightly controlled (weaker ontic relations), but there are strong boundaries between what qualifies as a legitimate approach and what does not (stronger discursive relations). Legitimacy is thus the result of using a specialized approach.
- *situational insight* (OR+, DR–): strongly bounds and controls what can be legitimately studied (stronger ontic relations) but weakly bounds how this can be done (weaker discursive relations). What is studied is

significant for legitimacy, but there is relative flexibility in terms of approaches used.

- *purist insight* (OR+, DR+): both legitimate objects of study and legitimate approaches are strongly bound and thus significant.
- *knower/no insight* (OR–, DR–): both the objects of study and the legitimate approaches are weakly bound. Thus, neither the object of study nor the method of study is used as a basis for legitimacy. This may be *knower insight* when these weaker epistemic relations are paired with stronger social relations (a knower code or ER–, SR+), or it may be *no insight* when paired with weaker social relations (a relativist code or ER–, SR–).

The *epistemic plane* is useful for distinguishing between the kinds of knowledge that are being developed (Maton 2014). One of the major complaints of employers of science graduates is that they are unable to apply their knowledge. Among many possible applications, the epistemic plane can be used to explain why this might be. Lecturers may focus on the use of particular methods but fail to clearly show the limits of their application. This means that students may be able to pass courses and apply specific approved methods (DR+) to solve problems carefully chosen by the examiners (could be OR– or OR+). However, on entering employment, the new graduate is likely to be faced with complex or multifaceted problems and must then decide which methods can be legitimately applied. If the limits of application, i.e. variation in strength of OR, was not a major consideration in the course, the new graduate may struggle.

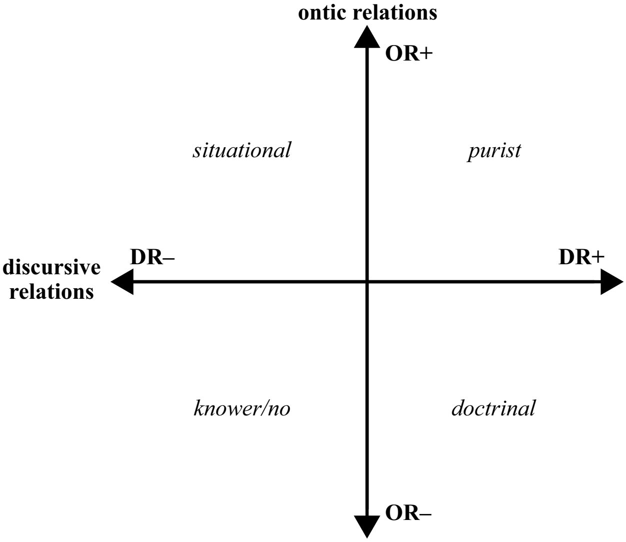

Figure 1.2 The epistemic plane (Maton 2014: 177).

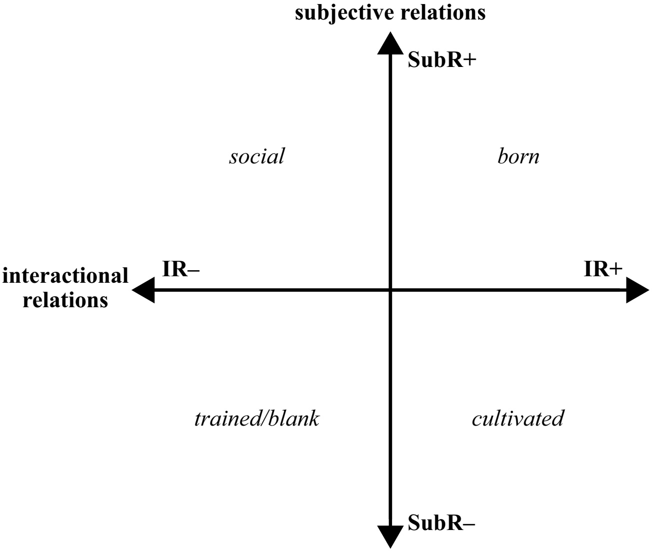

Figure 1.3 The social plane (Maton 2014: 186).

Turning to 'social relations,' the *social plane* (Figure 1.3) can be used to explore in greater depth different kinds of relations to knowers. These concepts are most applicable to knower-code practices (ER–, SR+) or élite-code practices (ER+, SR+), i.e. where social relations are relatively strong (Maton 2014). The social plane does not feature in this book. However, it is described here for the purposes of a more rounded introduction to the suite of tools most widely enacted at present. In addition, it affords the possibility of making the practices of knower-code fields (such as many parts of education research) more understandable to scientists. It may also be useful in science disciplines with a strong professional development orientation where social relations are also explicitly valued.

The *social plane* (Figure 1.3) maps the distinction between legitimation of practice on the basis of emphasis on who one is (*subjective relations*) and ways of knowing through interactions with significant others (*interactional relations*). Both can take many forms; for example, subjective relations may highlight social class, sex, gender, race, ethnicity, sexuality, religion, etc., and interactional relations may highlight prolonged immersion in a canon of great works, spending time within a culture and so on. Both relations may differ in how emphasized they are as the basis of legitimacy. As before, plotting these relations as a plane result in four modalities or *gazes*:

- *social gazes* (SubR+, IR–) emphasize legitimacy as a legitimate knower based on who one is (stronger subjective relations) and downplay the significance of specific ways of knowing (weaker interactional relations). An example is offered by standpoint theories that allow only those with a particular identity, such as being LGBTQIA+, to claim legitimacy.

- *cultivated gazes* (SubR–, IR+) emphasize legitimacy not on the basis of one's identity (weaker subjective relations) but rather on the basis of how one interactionally comes to be a knower (stronger interactional relations). These often involve acquiring a 'feel' for practices through, for example, extended participation in 'communities of practice,' sustained exposure to exemplary models, such as great works of art, and prolonged apprenticeship under an acknowledged master.
- *born gazes* (SubR+, IR+) emphasize both legitimate kinds of knowers (stronger subjective relations) and legitimate ways of knowing (stronger interactional relations), such as claims to legitimacy based on both membership of a social category and experiences with significant others (e.g. standpoint theory that additionally requires mentoring by already-liberated knowers in consciousness-raising groups).
- *trained/blank gazes* (SubR–, IR–) emphasize neither kinds of knowers nor ways of knowing as the basis of legitimacy. As part of specialization codes, they emphasize either stronger epistemic relations (trained gaze) or nothing at all (blank gaze).

Semantics

The Semantics dimension of LCT considers the nature of meanings in terms of context and complexity. The organizing principles are *semantic gravity* and *semantic density* (Maton 2014).

Semantic gravity (SG) refers to the degree to which meaning relates to its context (Maton 2013, 2014; Maton *et al.* 2016). Semantic gravity can be stronger and weaker along a continuum of strengths. When the meaning is strongly tied to a context, semantic gravity is stronger (SG+); when meaning is weakly tied to a context, semantic gravity is weaker (SG–). In practice, semantic gravity can be strengthened by moving from more decontextualized meanings to more concrete, contextualized meanings and weakened by doing the opposite. In science teaching, for example, real-world applications of theoretical concepts can be employed to strengthen semantic gravity, and then returning to the theoretical concepts would weaken semantic gravity.

Semantic density (SD) refers to the complexity of meaning (Maton 2013, 2014; Maton *et al.* 2016). Semantic density can also be stronger or weaker along a continuum of strengths. Stronger semantic density (SD+) indicates more complex meanings; weaker semantic density (SD–) indicates less complex meanings. In practice, semantic density can be dynamized by moving (strengthening and weakening) between more complex, condensed meanings and simpler meanings. In science teaching for example, when a scientific term or concept is introduced or used, the meaning is often relatively complex or stronger semantic density; when the lecturer then unpacks and explains these meanings using simpler words and terms, they are expressing weaker semantic density; then they return to the concept; they are moving back to stronger semantic density.

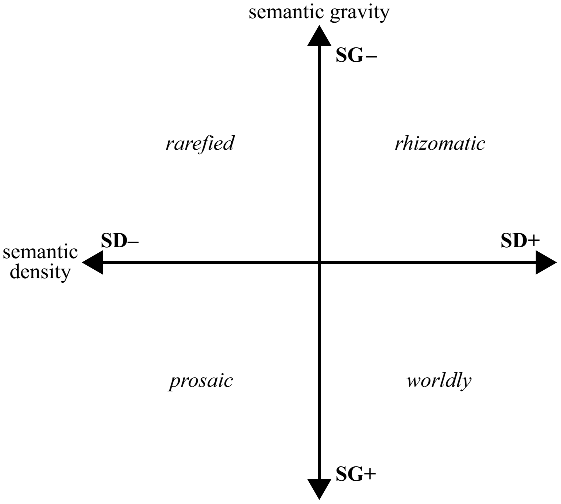

Figure 1.4 The semantic plane (Maton 2014: 131).

The strengths of the two organizing principles, *semantic gravity* and *semantic density*, may vary independently. These are mapped on the *semantic plane* (SG±, SD±): semantic gravity is the *y*-axis and semantic density is the *x*-axis, as shown in Figure 1.4 (Maton *et al.* 2016). We can identify four principal *semantic codes* (Maton 2013, 2014; Maton *et al.* 2016):

- *rhizomatic codes* (SG−, SD+), where meaning and the 'basis of achievement' is relatively context-independent (weaker semantic gravity) and complex and condensed (stronger semantic density). Examples in science education may include complex theoretical terms or abstract concepts, often expressed in specialist scientific language or symbols, where no external context is given or available.
- *worldly codes* (SG+, SD+), where legitimacy is based on meanings that are relatively context-dependent and more concrete (stronger semantic gravity) but complex and condensed (stronger semantic density). An example in science teaching may include teaching or using complex scientific terms or concepts taught against a backdrop of a real-world context.
- *prosaic codes* (SG+, SD−), where legitimacy represents meanings that are relatively context-dependent (stronger semantic gravity) and simpler (weaker semantic density). Examples of these codes in science teaching may include using simpler meaning (possibly everyday concepts or basic scientific terms) that apply to real-world contexts – maybe as a way to explain more complex content later in a lecture.
- *rarefied codes* (SG−, SD−), where legitimacy is based on meanings that are more context-independent (weaker semantic gravity) but relatively simple (weaker semantic density). Here, examples in science teaching may include the use of simpler theoretical terms, but without the

background of context (decontextualized), possibly purely theoretical, but relatively simpler meaning.

Practice (such as classroom practice) can and should ideally display code shifts on the semantic plane – movements between decontextualized and more contextualized meanings, as well as between simpler and more complex meanings. This shifting between semantic codes is known as *semantic waves* (Maton 2013, 2014). For example, Mouton and Archer (2019) have shown how pedagogy in Biology should enact semantic waves to facilitate cumulative learning and Mouton (2020) further showed how project-based learning can be employed to reach the same goal. Similarly, Blackie (2014) argues that many lecturers (organic Chemistry in her case) use terms and simply presume that students understand the broader scope of what is being said. Instead, lecturers should consciously and intentionally move between stronger and weaker semantic gravity, as well as between stronger and weaker semantic density, to enact semantic waves in their teaching of such theoretical/abstract discipline content.

Extensive research of classroom practices showed that the use of *semantic waves* enables cumulative knowledge-building (Maton 2013; Clarence 2016; Kirk 2017), a key aspect in ‘connecting the dots’ of knowledge. Clarence (2016) showed that Semantics can be used by lecturers to understand how to facilitate cumulative knowledge-building using semantic waves. In the field of academic writing, Kirk (2017) demonstrated how students can be taught to use the concepts of semantic gravity and semantic gravity waves to understand what is valued and required in their writing assignments. Matruglio *et al.* (2013) used the interesting approach of temporality in classroom practice to enact semantic waves.

The extent to which students are able to enact semantic waves in discourse has been shown to play a role in achievement (Maton 2013). Research revealed that high-achieving student essays are characterized by a wider semantic range than that of low achieving essays, which often display so-called semantic flatlines – little or no movement between simpler, contextualized and more complex, decontextualized meanings (Kirk 2017). However, this depends on the questions asked or the aims of a project. Georgiou’s studies (2016) in Physics education showed that students lacking experience in science (more novice learners) expressed a very limited range of semantic gravity in explanations, often remaining at the very concrete levels of stronger semantic gravity. Students with a stronger science background seem to understand that a wider semantic gravity range is needed to explain and answer certain questions. They also found that more proficient students understood which questions required a certain range for semantic gravity. However, less proficient students were found to often draw on explanations too weak in semantic gravity, thus reaching up the semantic gravity scale even when it is not necessary, revealing their lack of discernment.

Using the Semantics dimension of LCT to enact semantic waves in science education has vast potential to improve pedagogy and promote students’ learning, understanding and achievement. In science lecturing, for example, lecturers may reach back to discipline content from school but also stretch toward the new complex discipline content and move between abstract theory and applications in recurrent cycles. In this type of classroom practice, knowledge is continuously transformed between relatively concrete and decontextualized meaning, as well as between simpler and more complex condensed meaning, leading to the ability to build on previous knowledge and the transfer thereof into new contexts – crucial in science education.

Scientific language is generally complex and therefore represents stronger semantic density. However, ‘complexity’ is a relative term and is often used simply to refer to the cognitive demand of an assessment or assignment. In contrast, ‘semantic density’ affords greater specificity, conceptualizing complexity in terms of the condensation of meaning within practices, where condensation refers to adding meaning to a term or practice. Maton and Doran (2017a, 2017b) distinguished between forms of semantic density and explored *epistemic–semantic density* (ESD) which deals with epistemological condensation of formal disciplinary definitions and descriptions. They offer different tools for analyzing the ESD of language at the level of individual words, word-grouping, clausing and sequencing. Epistemic–semantic density further explores the relationality of meanings. Thus, the greater the number of relations to other meanings of terms or concepts, referred to as a *constellation* of meanings, the stronger the epistemic–semantic density (Maton 2013; Maton and Doran 2017b). For example, a scientific term such as ‘protein synthesis’ includes actions and processes with multiple distinct parts, each with its technical meaning, and will therefore have stronger ESD.

Autonomy

The Autonomy dimension of LCT explores the degree of insulation of practices — how insulated are the parts, and how insulated are the ways that they are related together (Maton and Howard, 2018). The two organizing principles are *positional autonomy* (PA) and *relational autonomy* (RA). Autonomy is based on the assumption that any set of practices comprises both constituents (the things in the practice, i.e. concepts, ideas, artefacts, actors) and relationships among those constituents (e.g. procedures, conventions, aims).

The degree to which a constituent in a particular context is insulated from constituents in other contexts is conceptualized as *positional autonomy* – the greater the degree of insulation, the stronger the positional autonomy (Maton and Howard, 2018). In education, this is often used to distinguish between what is seen as part of, or ‘inside,’ a specific knowledge practice and what is not. Those things that are taken to be ‘inside’ a practice are defined as having stronger positional autonomy (PA+), and those considered to be ‘outside‘ are defined as having weaker positional autonomy (PA–). For example, it can be used to analyze whether ideas are coming from within a specific topic of science (PA++), wider scientific knowledge (PA+), other academic knowledge (PA–) or everyday understandings (PA– –).

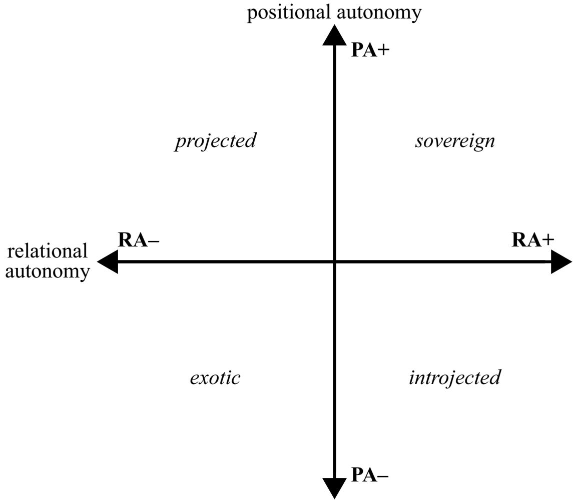

Figure 1.5 The autonomy plane (Maton and Howard 2018: 6).

The degree to which the principles governing the relations among constituents are bound by the field is conceptualized as *relational autonomy* (Maton and Howard, 2018). In education, this is generally taken as the purpose of an activity. Purposes that are taken as a legitimate part of or 'inside' a specific practice are defined as having stronger relational autonomy (RA+) than those considered 'outside.' For example, it can be used to analyze whether the ideas being taught in a science classroom are being turned to the purpose of teaching science (RA+) or towards another purpose, such as behavioural management or engagement (RA–).

Mapping positional autonomy and relational autonomy on the autonomy plane generates four principal *autonomy codes* (Figure 1.5):

- *sovereign codes* (PA+, RA+) result from strongly insulated positions and autonomous principles – PA and RA are both relatively stronger. Such practices would use, for example, 'inside' concepts to teach or research 'inside' problems, such as using the concept of equilibria in Chemistry to determine the pH of a weak acid in a Chemistry experiment.
- *introjected codes* (PA–, RA+) result when weakly insulated constituents are used for strongly bounded purposes – i.e. when things from 'outside' are used for 'inside' purposes, such as using calculus (from Mathematics) to solve problems in Physics.
- *projected codes* (PA+, RA–) result when constituents are strongly insulated, but the principles or ways in which they relate are heteronomous. Thus, what is valued arises from within the context, but it is used for other purposes, or what is 'inside' is used for 'outside' purposes; for example, when Physiology concepts are used to evaluate the validity of a health benefit claim made by the food industry.

- *exotic codes* (PA–, RA–) arise when there are weakly insulated positions and heteronomous principles. For example, knowledge from a different context is used to achieve an end that is not related to the subject in hand, such as telling a joke to get the class's attention.

Autonomy codes have the capacity to be enacted in real-world practices, such as teaching practice. It has been shown that there should be a rationale behind the materials or practices that are selected, repurposed and connected (Maton & Howard 2018, 2020). Purposeful shifts on the autonomy plane lead to so-called autonomy tours that engage and cohesively integrate different knowledge practices or content. In contrast, poor instructional design creates pathways around the plane that leave different knowledge practices or content segmented and disconnected (Maton & Howard 2018, 2020). Thus, one can use autonomy codes to design how to incorporate different knowledge practices or content, such as real-world content from other fields into science classroom pedagogy.

The layout of this volume

Given that the primary intended audience for this volume is academics who teach within a specific scientific discipline, we decided that organization according to discipline would be most helpful. Thus, we included five categories – academic support in science, physical sciences, biological sciences, mathematical sciences and science education research. If you are new to LCT, it may help to start with the section associated with your specialty first. That way you will be familiar with the knowledge content of the subject which will make the power of the LCT analysis more visible. This approach may also lower the threshold to becoming familiar with the LCT dimensions. However, once you are familiar with those chapters, we strongly recommend that you venture out of your comfort zone into different subject areas. This will both strengthen your range of understanding of the problems encountered in science education and will improve your understanding of LCT. At the end of the volume, we have included a 'how to navigate' chapter (Chapter 12) for those who are just dipping their toes into education research. We hope this chapter will help you to lower the activation energy threshold into getting going with doing your own research.

Part I of the book is potentially useful to all readers as the focus is on academic support in science (Chapter 2). The study explores the role a reflective learning portfolio in a science access course plays in enabling students to become active, self-directed and independent learners. The reflective learning portfolio interventions focus on explicitly guiding and modelling appropriate learning practices and critical reflection about learning. Karen Ellery uses LCT's Autonomy dimension to analyze the reflective learning portfolio interventions and students' responses to them.

Part II of the book focuses on the physical sciences. In Chapter 3, Christine M. Steenkamp and Ilse Rootman-le Grange focus on assessments in an introductory Physics course at Stellenbosch University in South Africa. The authors describe a detailed analysis of the Physics exam papers using *semantic density*. Their focus was on the kinds of representation i.e., graphs, diagrams, equations, etc., and the complexity of language used in these exam papers. Results revealed that some kinds of representations and some types of questions have been unconsciously omitted from their assessments.

In Chapter 4, Zhigang Yu, Karl Maton and Yaegan Doran turn their attention to different kinds of representations found in Chemistry. They carry out an in-depth study of a Chemistry textbook to reveal the levels of complexity and abstraction in operation in the diagrams. Using *epistemic–semantic density*, they develop a new method of analyzing representations in Chemistry which can be adapted to other sciences. The main aim of the chapter is to show how epistemic–semantic density can be applied to visual representations. Whilst much attention is given to symbols and nomenclature in Chemistry education, the complexity of visual representation is relatively rarely the focus of a study. Chemistry educators can tend to presume that a diagram automatically makes the content more accessible. By showing the variation in the complexity of representations in Chemistry, this chapter challenges that assumption.

In Chapter 5 Bruno Ferreira dos Santos, Ademir de Jesus Silva Júnior and Eduardo Fleury Mortim focus on high school Chemistry. They looked at the language used by the teacher, analyzing the clustering of words and phrases. Using recordings of lessons, they show the ways in which different teachers use language in the descriptions of chemical concepts. The variation is between highly dense technical language and much simpler more accessible language. The study defines various levels between these two positions using *epistemic–semantic density*. The study shows that some teachers repeatedly move between these two positions, whilst others achieve relatively little movement.

In Chapter 6, Lizel Hudson, Penelope Engel-Hills and Chris Winberg turn their attention to a Physics course presented as part of a degree in Radiation Therapy. Teaching the fundamentals of science to health sciences students who are eager to focus on patient care, is a non-trivial challenge. This chapter explores why these students may find it difficult to understand why they need to study Radiation Physics and why the subject is challenging. This chapter suggests ways in which the notion of threshold concepts can be used to make the fundamental science more accessible. This chapter also uses Specialization to make visible the challenges of teaching a subject with a very strong theoretical foundation to a cohort who are primarily interested in learning about patient care.

Part III of the book focuses on the biological sciences which here features an introductory Biology course, a senior Physiology course and a blended course comprising Anatomy and Physiology aimed at health science students.

In Chapter 7, Gabi de Bie and Sioux McKenna look at a course entitled ‘Human Biology’ which has developed from the amalgamation of Anatomy and Physiology courses for health sciences students. They show the ways in which integrative knowledge-building was overlooked in curriculum design resulting in a segmented course which fails to prepare students adequately for more advanced courses which draw on the foundational knowledge presented in this course. They use Specialization and Semantics in this chapter.

Chapter 8 is authored by Marnel Mouton, Ilse Rootman-le Grange and Bernhardine Uys. They explore why Biology students find it challenging to engage with complex disciplinary text from sources such as textbooks and then demonstrate their mastery of the subject matter using appropriate scientific discourse. They draw on LCT's concept of *epistemic–semantic density* (ESD) to analyze sections of the first-year and school textbooks, as well as students' written discourse from summative assessments. They show the profound variation that exists in the proficiency of the students' scientific vocabulary and language functions, as well as the discourse of the school and first-year Biology textbooks. They consequently argue for science pedagogy that would allow students time and opportunities to develop these crucial skills. Such practice may enable students to successfully engage with the subject matter and then communicate their understanding using written discourse.

In Chapter 9, M. Faadiel Essop and Hanelie Adendorff focus on using Autonomy to analyze a project-based activity in the context of an undergraduate Physiology course. The goal of the activity was to teach students how to do science as opposed to teaching them about science. Exploring what is introduced and for what purpose, using Autonomy, show the value and dangers involved in these kinds of activities. One can spend a lot of effort on marginal activities which in fact may obscure the epistemic content necessary within the subject.

Part IV of the book turns to the mathematical sciences featuring a chapter on the transition into second-year Mathematics and a chapter applicable at all levels of tertiary study focusing on mathematical knowledge.

In Chapter 10, Ingrid Rewitzky focuses on teaching Mathematics guided by the epistemic plane. It is one of the more subject-specific chapters in the book but serves as a very useful introduction to the power of the epistemic plane in making the different kinds of knowledge used in Mathematics visible in teaching. To those without some tertiary-level Mathematics, it will require a bit of digestion, but it will be well worth your time investment. This chapter is groundbreaking and will be applicable to engineering disciplines as well.

In Chapter 11, Honjiswa Conana, Deon Solomons and Delia Marshall look at the transition from first year to second year in Mathematics. At many South African institutions, there has been significant investment in improving the first-year experience, but the transition into the second year of study can prove to be a stumbling block. In this chapter, they interrogate the experiences of both students and lecturers of a particular intervention introduced to smooth this transition in Mathematics.

The final chapter in Part V is written by Margaret A.L. Blackie and is aimed at helping those new to science education research to get something of a foothold in the new terrain. The beginning of the chapter gives a brief overview of critical realism. Whilst critical realism is one theoretical framework among many, it is a useful starting point for those entering education research from a background in disciplinary research in a STEM field. This foundation is then used to situate LCT as realist sociological theory. The second part of the chapter gives some pointers on how to begin using LCT in the scholarship of teaching and learning.

Overall then, this volume provides an overview of what can be achieved using LCT in science education. Represented here are a diversity of science fields from high-level Mathematics to service courses in Biology. In addition, all the major LCT dimensions which have been developed to date and are likely to be applicable to science educators are represented here. Thus, this book provides a solid introduction to the use of LCT in science in particular and will be useful to educators and researchers across STEM fields more generally.

Note

1 For this growing body of work, see the database of LCT publications at https://legitimationcodetheory.com/publications/database/.

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