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THE TEACHING OF SCIENCE

New insights into knowledge, language and pedagogy

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Introduction

Science is significant. Faced with the climate emergency, global pandemics and proliferating threats to life on Earth, that significance should go without saying. However, science is under sustained attack by irrationalism in politics, the news and social media. The need for science education has never been more urgent. Yet, in many advanced societies, science is struggling to attract and retain students through school and university. One problem facing attempts at addressing these issues is a tendency for studies to obscure the knowledge and language that comprise science. The subfields of education research dedicated to science disciplines have contributed greatly to our understanding of *scientific ways of knowing*. Studies explore the cognitive resources, perceptions and judgements of students and the processes of learning. They are extensively examining the conceptions, motivations and dispositions that students bring to learning science and the ways of thinking exhibited by students when learning science. However, *what* students are learning when they study science, the nature of the *scientific knowledge* itself, receives far less attention. Moreover, this dominant focus on how students learn science has been accompanied by neglect of the teaching of science. Pedagogy is too often reduced to an afterthought of findings about how students think. Without understanding how scientific knowledge and language may help shape the best ways of teaching that knowledge, we have only part of the picture. This volume aims to help fill this gap by exploring the knowledge practices and multimodal discourses of science teaching.

The collection extends two approaches that make pedagogic discourse a central object of study in education: Legitimation Code Theory (LCT) and Systemic Functional Linguistics (SFL). These approaches bring to light the meaning-making activities of social actors, in complementary ways. LCT is a sociological framework that foregrounds the knowledge practices of science education, revealing features such as their complexity, context-dependence, boundedness and specialized procedures. SFL explores the language and other semiotic resources, including mathematics, images and gesture, through which these knowledge practices are expressed. In recent years scholars and educators using these two frameworks have been closely working together, generating a fast-growing body of work that draws on both sides of this genuinely interdisciplinary dialogue (e.g. Martin and Maton 2013, Martin *et al.* 2020b). This book builds on this collaboration to offer cutting-edge developments in both approaches that will generate major advances in not only how science education is understood but also how knowledge, language and pedagogy are conceived more widely.

Teaching Science is organized into three parts. Part I draws on LCT to explore how science teaching can support knowledge-building. A series of innovative studies focus on the integration of mathematics into science (Chapter 2), the building of scientific explanations (Chapter 3) and the integration of multimedia such as animations into science teaching (Chapter 4). These studies introduce new concepts and new methods in LCT, including 'autonomy tours' (Chapter 2), 'constellation analysis' (Chapter 3) and 'epistemic affordances' (Chapter 4).

Part II greatly extends SFL to explore the multimodal discourses that underpin knowledge-building in science classrooms. These chapters articulate the expansive range of meanings involved in explaining complex scientific phenomena (Chapter 5), the ways in which deep scientific taxonomies are built (Chapter 6), and the essential interdependence of language, mathematics and images in scientific knowledge (Chapter 7). They advance the modelling of meaning-making in SFL into new areas and articulate extensions to concepts that will kickstart new forms of research into science discourse, including 'field' (Chapter 5), 'ideational discourse semantics' (Chapter 6) and the multimodal analysis of language, mathematics and image (Chapter 7).

Part III explores the practical implications that LCT and SFL analyses can deliver for teaching science. Chapters discuss how access to scientific knowledge can be widened to a greater diversity of students (Chapter 8), how knowledge is transformed to address real-world problems in engineering design (Chapter 9), the meanings communicated in live lectures that are rarely taken into account in debates over pedagogy (Chapter 10), and how mathematics can be taught effectively to all students through the influential pedagogic program 'Reading to Learn' (Chapter 11).

In this opening chapter we introduce the book by outlining the traditions of studies enacting the frameworks of LCT and SFL to examine science education. First, we locate this volume in the long-standing body of work using SFL to understand talking, writing and reading science. Second, we turn to the more recent but growing body of research and practice enacting LCT to examine and shape teaching and learning science. Finally, we introduce the chapters of this book, highlighting how they offer new ways of understanding, analyzing and shaping science teaching.

The language of science

Systemic Functional Linguistics (SFL) is a major linguistic approach that has developed worldwide since the 1960s. SFL explores how language is used in social life to organize our interpersonal relations, manage the content meanings we want to express and bring this together to make coherent text. Scholars using the approach consistently emphasize the need to study language in a way that contributes to improving the world. This emphasis on 'appliable' linguistics means SFL engages with a very wide range of contexts and uses of language. One of its longest engagements has been with scientific discourse. At first this was not to examine science itself but rather to understand English grammar (Huddleston *et al.* 1968). Since the 1980s, however, SFL engaged more deeply with scientific texts educationally, from the perspective of teaching literacy in science. At the time, researchers were dissatisfied with prevailing approaches to literacy that emphasized writing without explicitly modelling the language patterns that students need to learn. In response, SFL scholars began developing ways of explicitly teaching differences in writing across subject areas, an approach which became known as 'genre pedagogy' (Rothery 1989, Rose and Martin 2012).

However, to teach the specific language patterns used in different subjects, educators needed to know those patterns. This necessitated a large-scale descriptive effort to map language features across the disciplinary spectrum, much of which was funded by the Metropolitan East Disadvantaged Schools Program in Sydney, Australia. A key focus of this work was to analyze the language of science using concepts from across the SFL framework. An early concern was with text types and text structures of science, conceptualized in terms of *genre*. This work is illustrated by the book *Factual Writing* in which Martin (1985) presented descriptions of different genres in primary school scientific texts, including *reports* that generalize experiences about things, *procedures* that focus on how to make things happen, and *explanations* that explain things.[1]

Through the late 1980s and 1990s these models of genre in science were greatly expanded as SFL researchers engaged with later primary school, secondary school and workplaces associated with science and technology (e.g. Rose *et al.* 1992, Unsworth 1997a, 1997b, 1997c, Veel 1992, 1997). This work formed part of major innovations in SFL as a framework that transformed linguistic modelling of not only scientific discourse but also language more broadly. Many of these innovations are brought together in a series of landmark books on talking, writing and reading science. *Talking Science* (Lemke 1990) engaged in depth with language and meaning-making in science education for the first time. *Writing Science* (Halliday and Martin 1993) offered significant advances in the grammatical modelling of scientific language and insights into the nature of scientific meaning and technicality from the perspective of the register variable *field*. *Reading Science* (Martin and Veel 1998) collected papers significantly expanding the reach of SFL research into science, including popular science, environmental discourse, and both pedagogic and workplace settings, as well as exploring features of scientific discourse such as grammatical metaphor and multimodality. These books laid foundations for subsequent SFL research into science and fed back into the development of pedagogic programs through SFL. Many of these programs have aimed at designing classroom practices and resources for improving the teaching of both the content of any particular subject area as well as the literacy practices so necessary for organizing this content. This has included developing frameworks for teaching students language about language ('metalanguage') so they can more easily talk and reflect upon their reading and writing, and designing classroom practices that enable a gradual handover of scientific ways of reading and writing from teachers to students (Unsworth 2001, Christie and Derewianka 2008, Rose and Martin 2012, Derewianka and Jones 2016, Dreyfus *et al*. 2016, Humphrey 2017). These programs have been internationally influential, underpinning among other things, the current Australian literacy curriculum. Underpinning this book, the interaction between SFL research into scientific discourse and its pedagogic development highlighted three key areas of ongoing exploration: the grammar of scientific language, technical meanings in science and the multimodal nature of science.

The grammar of scientific language

In *Writing Science*, Halliday (1993a) highlighted significant differences in the language used in science compared to that of other registers. Scientific language, he summarized, involves:

- *interlocking definitions,* where technical terms are mutually defining;
- *technical taxonomies*, where terms are ordered into complicated layers of classification and composition;
- *special expressions*, where large multi-word constructions are technical, rather than simply individual words;
- *lexical density*, where there is a relatively high number of lexical words per clause;
- *grammatical metaphor,* where a grammatical structure is 'mismatched' with its meaning, such as when the clause 'how quickly cracks in glass grow' is reconstrued as the nominal group 'glass crack growth rate';
- *syntactic ambiguity*, where grammatical forms produced by grammatical metaphor lead to ambiguity in their meaning; and
- *semantic discontinuity*, where steps in the logic of reasoning or specific links connecting technical meanings are presumed or not made explicit.

These individual language features, Halliday points out, are regular occurrences in scientific texts and perform distinct functions in the organization of technical meaning. Through the history of scientific discourse, these grammatical features evolved in conjunction with scientific knowledge. To construe new meanings of scientific thought, scholars such as Chaucer, Newton, Maxwell and Darwin required new forms of English. Over time, these 'new forms of English' became the dominant motif for scientific texts (Halliday 1993b, 1993c, Banks 2008, 2017). However, when a number of these language features are used together in the same text, they can make scientific language difficult for learners – they are 'grammatical problems'.

In terms of linguistic modelling, the grammar of science raised questions regarding the nature of language in general. One key issue in particular was the nature of grammatical metaphor (Simon-Vandenbergen *et al*. 2003). Grammatical metaphors involve meanings being reconstrued in an 'incongruent' manner. For instance, in the example given by Halliday noted above, 'how quickly cracks in glass grow' is reconstrued as a grammatical metaphor through the nominal group 'glass crack growth rate'. Metaphors such as these were shown to be key in moving into the language of school science and other subjects (Derewianka 2003). But how one can show that something is a grammatical metaphor rather than a 'normal' realization of a meaning was less clear (Halliday 1998). For example, in biology the word 'phagocytosis' is a noun, yet it seems to construe an 'event' in some sense because it names the process whereby pathogens in the body are engulfed and destroyed. However, unlike 'glass crack growth rate', it cannot easily be turned back into a more 'congruent' form – it is rare, if indeed it happens at all, for biology textbooks to talk about 'phagocytosing' as a verb. These more theoretical and descriptive questions led to a refocus on how SFL could model semantics in relation to grammar. Among other things they influenced the highly elaborated model of ideational semantics put forward by Halliday and Matthiessen (1999), which has in turn laid a platform for the discourse semantic modelling of Hao (2020b, Chapter 6 of this volume) and has shed further light on how grammatical metaphors work (Hao 2020a, Martin 2021).

For educational research, this work gave a sense of the language patterns students needed to write. However, it was clear that many subject areas valued getting the technical 'content' meanings correct over other linguistic patterns. Although concerns for genre and grammar were important, this was only to the extent that they were used in service of the technical meanings of science. This raised the question of what a 'successful' text in science education is, and more broadly how to model scientific meanings in general.

Technical meanings in science

To understand how technical meanings are organized in science, the grammatical and genre perspectives on scientific language in SFL were coupled with a perspective of *field* within SFL. Field is a variable of register (following the stratal model of Martin, 1992) which is realized by ideational meaning in language and notionally organizes the 'content' meanings of discourse. In the 1980s, one of the key issues for SFL scholars was the large taxonomies of technicality in science with which students must engage (a field perspective on one of Halliday's 'grammatical problems'). This required renovating existing SFL descriptions of field to make a series of key distinctions. First, taxonomies were modelled as being either of classification, relating things in terms of type–subtype, or of composition, relating things in terms of part–whole relations. Different text types emphasized different types of taxonomy, and as Wignell *et al*. (1993) argued in *Writing Science*, different fields could also be distinguished by exploring their taxonomies. For example, in the specialized field of bird watching, taxonomies of birds tend to be more elaborated than those typically used in everyday life. However, these taxonomies share the fact they both tend to be based on observable characteristics of birds, such as colour, markings, size, habitat, etc. In contrast, the scientific taxonomies of ornithology, in addition to being significantly more elaborated, are based on shared lineage shown through genetic comparison and requiring specialist equipment, rather than observable characteristics. This renovated model enabled texts to be explored in terms of the field-specific meanings they presented. However, a key issue that remained was how language is used to *build* these taxonomies. Chapter 6 of this volume (Hao) takes a major step forward by laying out an extended model of 'ideational discourse semantics' for understanding how highly elaborated taxonomies are built in biology.

A second distinction concerned the intricate sequences of events known as *activities* that often occur in explanations and procedures. In contrast to many fields, activities in scientific fields are often linked by 'implication' where an activity necessarily implicates another activity. An example of this from Wignell *et al.* (1993) concerns *convective uplift*:

> Convective uplift
> Air in contact with a warm surface will become heated and expand causing it to rise. Dew point will be reached, condensation will take place and convectional clouds will form.

This text presents a series of activities that are related by implication, where one necessarily follows another (here ^ indicates sequence):

Air in contact with a warm surface will become heated
^
and expand
^
causing it to rise
^
Dew point will be reached
^
condensation will take place
^
and convectional clouds will form

Each step in this series necessarily occurs because of the previous step. This contrasts with series of activities in genre such as stories where events tend to occur in a less definite fashion – things can 'go wrong' and unexpected events may occur (indeed this is one of the key features of stories, Martin and Rose 2008). As the text above shows, these activities may include technical terms (dew point, condensation, convectional clouds) that may be positioned within the taxonomies of scientific discourse, while the whole sequence itself is named technically as 'convective uplift'. Such naming of activities, alongside elaborated taxonomies and extensive use of grammatical metaphor, was shown in *Writing Science* to underpin the enormous technicality of science.

This model of field has informed decades of research into scientific discourse and has proven both a relatively intuitive means of understanding technical meaning and one that can be linked with language patterns. However, it still did not account for many areas of scientific meaning, including the various gradable properties (size, weight, force, etc.) that often distinguish items in taxonomies and in later years of secondary school are often realized through mathematics and graphs, nor how the various aspects of field (taxonomy and activity) could be integrated into a coherent 'whole' to explain or describe phenomena. Taking these issues as its point of departure, Doran and Martin (Chapter 5, this volume) directly build upon this model of field to encapsulate a wider range of scientific meaning-making that has been highlighted by research in recent years.

Multimodality in science

Running parallel to studies of grammatical, genre and field-based attributes of science has been a focus on the *multimodal* nature of its discourse. Books such as *Reading Images* (Kress and van Leeuwen 1990) opened the way for linguists to engage with semiotic resources beyond written language. The work of Kress and van Leeuwen (1996) on scientific diagrams, for example, showed that images were organized in highly conventional ways that could be analyzed in terms comparable to both the field and grammatical modelling being developed for language. This highlighted the importance of multimodal meaning making in science education and in broader schooling contexts, and heavily influenced the turn towards 'multiliteracies' in education. School literacy is no longer considered just reading and writing language but also viewing, drawing and organizing images, and a range of other meaning-making systems (New London Group 1996, Unsworth 2001, Kress *et al.* 2001). Understanding how individual semiotic resources enable this to happen became a key question for SFL multimodality researchers. Work on images along these lines has continued steadily since the 1990s, accelerating recently in relation to the role graphs play in science (Doran 2018a, 2019, Chapter 7 of this volume), the significant degree of meaning organized into scientific diagrams (Unsworth 2020, Martin *et al.* 2021, Doran 2019), the use of certain types of image as technical formalisms across disciplines (Yu in press, Doran 2020), and how images are dynamized into animations for teaching science (He 2020).

In addition to images, the advent of multimodality encouraged further developments for other semiotic resources. For science a key step forward in this regard was O'Halloran's (2005) work on mathematics, which began to fill a major gap in our understanding of scientific discourse. Along with work by Lemke (1998, 2003), this work emphasized that multimodal texts were more than the 'sum of their parts'. Although each semiotic resource organized its own meaning, these meanings were 'multiplied' (Lemke 1998) when used with other semiotic resources in a text to make new meanings not available to any individual resource. O'Halloran's study put forward for the first time an operationalizable description of how different semiotic resources of language, mathematical symbolism and images worked not only individually but also in terms of their interactions or 'intersemiosis'. This focus on intersemiosis has laid the groundwork for ongoing work in systemic functional work on science education. For example, Doran's (2018a, 2018b) model of mathematical symbolism built on O'Halloran's work to develop a fully systematized grammatical description of mathematical symbolism used in secondary school and university physics. It also explored the interaction between language and mathematics in terms of the genres these two resources realized together. This in turn raised theoretical questions about the modelling of semiotic resources outside of language. In particular Doran questioned the general assumption that the three metafunctions – ideational, interpersonal and textual – occur for all semiotic resources (e.g. Kress and van Leeuwen 1996, O'Halloran 2005). Doran (2018b) argued that when descriptions did not assume it, there was no evidence for identifying an interpersonal metafunction in mathematical symbolism. This work on symbolisms is currently being extended by Yu (in press), focusing on chemistry discourse, which is helping to open space for engagement with the highly technical texts of upper secondary school science. A number of chapters in this volume directly extend SFL work on multimodality, including Chapter 7 (Doran) on the interaction of mathematics, images and language in physics, Chapter 10 (Hao and Hood) on interactions between body language and language in chemistry lectures, and Chapter 11 (Rose) on teaching mathematics.

Alongside the aforementioned advances in understanding grammar and technicality, this move towards multimodality helped transform the SFL understanding of science between the late 1980s and early 2000s. New models of language and semiosis were generated that opened the way for new objects of study and drove new pedagogic applications. More recently, a further transformation has been taking place in how SFL approaches science education, one sparked by an ongoing dialogue between SFL and Legitimation Code Theory.

The knowledge of science

Legitimation Code Theory (LCT) is a framework for analyzing and shaping practices.[2] LCT integrates and extends insights from a range of influences but most explicitly builds on the sociological frameworks of Pierre Bourdieu and Basil Bernstein (see Maton 2014, 2018). Like SFL, LCT is concerned with the meaning-making activities of social actors. As its name implies, LCT provides tools for exploring the bases of legitimacy or 'rules of the game' in social fields, in ways that reveal the organizing principles underlying practice. Metaphorically, LCT gets at the DNA of practice.

Reflecting its sociological foundations, LCT views society as comprising relatively autonomous social fields of practice (such as law, medicine, education, etc.) that have distinctive resources and forms of status. In each social field, actors cooperate and struggle, both for more of what is viewed as signs of success and over what defines success in that social field. Their practices thus embody messages as to what should be dominant measures of achievement. This is to highlight that there is more to what we say or do than what we say or do. For example, if a teacher has a class undertake a practical experiment, they are teaching not only whatever scientific content the experiment imparts but also that engaging in concrete, tangible activities is important and that students discovering results by themselves is important. LCT reveals these kinds of messages by analyzing the organizing principles of practice.

These organizing principles can be manifold. Any set of practices has a diverse range of characteristics, such as their complexity, context-dependence, emphasis on specialized knowledge or personal experience, boundedness from other practices, and so forth. The organizing principles underlying practices are conceptualized by LCT as different species of *legitimation code*. The conceptual framework is structured into a series of *dimensions* or sets of concepts that each explore a distinctive species of legitimation code. There are currently three active dimensions – Specialization, Semantics and Autonomy – centred on exploring specialization codes, semantic codes and autonomy codes, respectively.[3] Put simply, Specialization explores how knowledge and knowers are articulated within practices, Semantics explores questions of context and complexity, and Autonomy explores where contents and purposes of practices come from. (On Specialization, see Maton 2014, 2020; on Semantics, see Maton 2013, 2014 and Maton and Chen 2020; on Autonomy, see Maton and Howard 2018, 2020, and Chapters 2 and 4 of this volume. For how LCT concepts relate together, see Maton 2016). These different dimensions do *not* refer to different sets of empirical practices but rather offer ways of revealing different organizing principles underlying the same set of practices. How many and which dimensions are drawn on in empirical research depends on the problem-situation (specific questions concerning a particular object of study).

LCT and science education

Scholars and educators are enacting LCT to examine and shape practices across the disciplinary map and in all kinds of educational institutions, as well as beyond education (e.g. Maton et al., 2016a; Winberg *et al.* 2021). The framework is widely applicable and studies of topics far beyond one's own substantive areas of concern can offer insights. For example, in developing the concept of 'constellations' to analyze the teaching of scientific explanations, Maton and Doran (Chapter 3, this volume) found constellation studies of ballet lessons, History courses and ethnopoetics all highly valuable. Thus, insights into science education offered by LCT research are not confined to studies expressly focused on that topic. Nonetheless, there is a growing body of work dedicated to exploring the teaching and learning of science using different dimensions of LCT either separately or in combination.

The dimension of Specialization is proving particularly valuable for exploring how knowledge and knowers come together in science education. For example, concepts from Specialization have opened up new ways of thinking about supporting 'epistemological access' to science knowledge for students from diverse social backgrounds (Ellery 2018, Chapter 8 of this volume). They are also providing practical tools for supporting engagement with decolonization in science education in ways that respect different ways in which knowledges and knowers are valued (Adendorff and Blackie 2021). Focusing on the 'knowledge' side, an interlocking series of studies led by Karin Wolff (e.g. Pott and Wolff, 2020, Wolff 2021) draw on the *epistemic plane* (Maton 2014: 171–195) to explore how teaching and learning emphasize in different ways the specialized procedures of engineering and/or the phenomena for which they are used. Combined with studies of issues from work-integrated learning (Winberg 2012) to student design projects for 'real world' problems (Wolmarans, Chapter 9, this volume), this work is building a sophisticated picture of engineering education.

The dimension of Semantics directly resulted from two major studies of teaching practices in secondary school science (see Maton 2020). Specifically, this work introduced the notion of *semantic waves*, which describes recurrent shifts in the context-dependence and complexity of knowledge, and the method of *semantic profiling* those changes over time (Maton 2013, Macnaught *et al.* 2013). These ideas are being successfully enacted across science education, including to support cumulative learning in chemistry (Blackie 2014), student transition from school to university biology (Mouton and Archer 2019), project-based learning in biology (Mouton 2019) and in chemistry (Veale *et al.* 2017), real-world applications in chemical engineering (Dorfling *et al.* 2019), student design practices in engineering (Wolmarans 2016), problem-solving in physics (Conana *et al.* 2021), and student assessments in chemistry (Rootman-le Grange and Blackie 2018) and physics (Georgiou *et al.* 2014; Steenkamp et al. 2019). Extending these concepts into exploring multimodality is also a burgeoning focus, such as the role of language, mathematics and image in physics (Doran 2018a).

Studies of science education have also played a crucial role in developing new concepts in the dimension of Autonomy. Research into teaching in science classrooms helped generate the notion of *autonomy tours* (Maton and Howard 2018), which shows how to successfully integrate science knowledge with other content and purposes, such as everyday experiences, metaphors, analogies and knowledge from other subjects. These are providing new ways of understanding how to successfully integrate mathematics and multimedia objects in science teaching (Maton and Howard, Chapters 2 and 4 of this volume).

Dialogue with SFL

A genuinely inter-disciplinary dialogue between LCT and SFL has been underway since the turn of the century. This collaboration built on and intensified previous discussions between Basil Bernstein (whose theory is a foundational framework for LCT) and Michael Halliday and Ruqaiya Hasan. This dialogue went through a series of phases (see Maton and Doran 2017). In the late 1990s, Bernstein's ideas were inspiring SFL scholars to think about knowledge structures in education (Martin *et al.* 2020a). The emergence of LCT in the early 2000s offered to SFL, among other things, a means of engaging more empirically with knowledge practices, in both research and teaching. This began a series of more intense phases of direct inter-disciplinary collaboration between LCT and SFL scholars. One result is a rapidly growing number of papers, books and doctoral theses that use both frameworks together to generate greater explanatory power (e.g. Martin *et al.* 2020b; Maton *et al.* 2016). In this volume, for example, Doran (Chapter 7) engages with both the LCT dimension of Semantics and the SFL register variable *field* to examine how language, image and mathematics come together in school physics. Another result is an ongoing series of innovations in each framework. For example, the LCT concepts of 'semantic gravity' and 'semantic density', which explore the context-dependence and complexity of knowledge practices, were in part stimulated by dialogue with SFL scholars. In turn, these LCT concepts provoked the development of new SFL concepts of 'presence' (Martin and Matruglio 2020) and 'mass' (Martin 2020), which bring together the many ways these issues are manifested in language. These new concepts have begun to show great promise in gathering together manifold linguistic resources in studies of science education (Hood and Hao, Chapter 10, this volume).

More generally, this dialogue with LCT has evoked in SFL research a growing interest in the role of linguistic and semiotic resources in knowledge-building. This focus is resulting in major theoretical advances. One recent example is Hao's development of ideational discourse semantics (2018, 2020a, 2020b), as illustrated by Chapter 6 of this volume. Building on Halliday and Matthiessen's (1999) description of ideational semantics, Hao has developed a model for exploring the ways that technical knowledge is built through unfolding discourse. This addresses an issue that had long vexed SFL scholars, with previous attempts at understanding discourse semantics regularly becoming blurred into either grammatical description or field-based description. Hao's model (Chapter 6) offers a clear and distinct descriptive level that enables a view of scientific language on its own terms. A second example, which complements Hao's work, is a newly extended model of field by Doran and Martin, as shown in Chapter 5 of this volume. Taken together with the expansive grammar of English put forward by Halliday (Halliday and Matthiessen 2014) and the models of genre developed for science (see Martin 1985, Martin and Rose 2008), this new period of research has enabled SFL to greatly expand our understanding of the rich and multifaceted language and multimodality inherent in science.

On *Teaching Science*

This volume offers major steps forward in how both LCT and SFL conceive science and science education. The title consciously echoes past landmark works in SFL, with *Teaching Science* capturing the principal focus of and stimulus for this new work. The subtitle, *Knowledge, language, pedagogy,* sets out the organization of the book into three main parts that explore: knowledge-building in teaching science; the multimodal discourses that underpin this knowledge-building; and how to improve the teaching and learning practices of science.

Part I comprises three chapters that develop new ideas in LCT to understand major issues in teaching science: the integration of mathematics (Chapter 2), the teaching of scientific explanations (Chapter 3) and the use of multimedia digital resources (Chapter 4). These chapters build on one another. **Chapter 2** (Maton and Howard) addresses the vexing question of how mathematics can be successfully integrated in science teaching. That students often struggle with mathematics in science lessons, even when they have little difficulty with those ideas in mathematics lessons, has been a long-running concern for educators. One reason this issue remains unsolved is that existing approaches cannot systematically distinguish 'mathematics' knowledge from 'science' knowledge. Maton and Howard introduce cutting-edge tools from the LCT dimension of Autonomy that enable knowledge practices to be distinguished without lapsing into either essentialist definitions that neglect how these bodies of knowledge differ between contexts or relativist claims that they are nothing but endless flux. The concepts are illustrated through detailed analyses of real-world classroom practices that show a key attribute of successful integration of mathematics in science teaching to be *autonomy tours* that shift between different contents and purposes in particular ways. The ideas outlined here are poised to have a major impact on both research and practice in education, far beyond science teaching.

Chapter 3 (Maton and Doran) focuses on the role played by relations among ideas in teaching scientific explanations. Reflecting their knowledge-blindness, dominant approaches to researching science education neglect the ways in which ideas are connected to create explanations. Maton and Doran introduce the method of *constellation analysis* from LCT as a way of revealing these relations among ideas. This innovative method is used to analyze explanations of the tides and seasons. In each case the logic of explanations presented in school textbooks is analyzed and compared to how the explanation is taught in a classroom. These analyses show that explanations of seemingly similar kinds of phenomena differ in terms of how ideas are related together and that the logic of these relations impacts on how they are taught in classrooms. Constellation analysis offers a new analytic method with huge potential as a practical tool for researchers, curriculum designers, educators and students.

Chapter 4 (Maton and Howard) examines how multimedia such as animations can be integrated into teaching science. Existing research overwhelmingly focuses on developing principles for designing multimedia that support cognitive processing of information. This chapter meets an urgent need to foreground teaching and knowledge as a first step towards developing pedagogic principles for teaching multimedia that support learning science. To do so, the chapter extends existing limited uses of the notion of 'affordances' to examine how the knowledge practices expressed by multimedia relate to those central to specific classroom tasks. These *epistemic affordances* are revealed through an innovative form of autonomy analysis that shows how the diverse elements of complex multimedia objects relate to the contents and purposes of specific classroom tasks. In-depth analyses of two contrasting examples of science teaching with animations show the pedagogic work required of teachers to integrate such multimedia and how LCT offers a way of getting to grips with these complex objects in real-world contexts.

Part II comprises detailed studies of the language and multimodal discourse of science teaching using newly-developed tools from Systemic Functional Linguistics. These chapters articulate the expansive range of meanings involved in explaining complex scientific phenomena (Chapter 5), the ways deep scientific taxonomies are built (Chapter 6), and the interdependence of language, mathematics and images in building scientific knowledge (Chapter 7). These three chapters push the modelling of language and meaning-making in SFL into new territory and articulate theoretical principles that will enable new forms of research into science discourse. They complement the LCT analyses of Part I to significantly expand our understanding of scientific knowledge and semiosis and how these are taught.

Chapter 5 (Doran and Martin) introduces an evolving model of the register variable 'field' for understanding the intricate explanations built in science. This explores how science can view phenomena from a static perspective in terms of elaborated taxonomies or a dynamic perspective in terms of unfolding activities. Doran and Martin also explore how large swathes of gradable properties can be arrayed and measured, and how all of these can be reconstrued and interconnected for any particular 'topic' in science. This description takes a big step forward in building upon decades of modelling of field in SFL and works to be generalizable across language, image, mathematics and a wide range of other semiotic resources.

This new model of field is being developed in dialogue with a new model of ideational discourse semantics that informs **Chapter 6** (Hao). This explores scientific meaning as it unfolds in text to create an intricate discourse semantic framework for grasping the elaborate taxonomies built in biology, and the various entities they marshal. Chapter 6 forms part of a larger discourse semantic model developed by Hao (2018, 2020a, 2020b) that significantly pushes forward knowledge of how scientific language organizes its technical meaning. Together with Chapter 5, this offers for the first time an expanded resource for modelling ideational meaning that links lexicogrammar, discourse semantics, field and genre.

Chapter 7 (Doran) explores scientific meaning as inherently multimodal. Focusing in particular on the interaction of mathematics, images and language in physics, Doran shows how each builds technical meaning in ways that can 'hand over' this meaning to others. Drawing on the SFL model of field developed in Chapter 5 and the dimension of Semantics from LCT, this chapter shows how semiotic resources are brought together to move from relatively common-sense meanings to technical, while at the same time moving between the empirical and the theoretical.

Part III exemplifies the close connection between research and practice that characterizes LCT and SFL research into science teaching. These chapters draw on LCT and/or SFL to explore how more students can be supported to access scientific knowledge (Chapter 8), the vexed problem of simplifying 'real world' problems to teach professional reasoning in engineering education (Chapter 9), the role of body language in face-to-face chemistry lectures (Chapter 10), and methods for teaching mathematics to enable all students to learn (Chapter 11).

Chapter 8 (Ellery) examines a science foundation course that is intended to support more students to successfully engage with learning science at university. Enacting the Specialization dimension of LCT to explore curriculum, staff beliefs and student experiences, Ellery shows that the course involves two different bases of achievement. One basis requires students to demonstrate their understanding of scientific knowledge, the other requires students to be a particular kind of scientific knower. Moreover, students must be the right kind of knower in order to access the right kinds of knowledge. Ellery uses LCT to dig beneath the surface of curricular intentions and show how educational practices may contradict those intentions. The chapter poses a significant challenge to current thinking about how more students can be supported to access science in education.

Chapter 9 (Wolmarans) problematizes the widely-held view of professional education, such as engineering, as learning how to apply disciplinary science knowledge to 'real world' problems. Enacting concepts from the Semantics and Specialization dimensions of LCT, Wolmarans analyzes design projects in a civil engineering course that are intended to authentically mimic professional problems. Such projects require simplification of the problem for students. The chapter pushes LCT analysis to distinguish between reduced complexity of the knowledge required by students to solve a problem and reduced complexity of the problem itself. Crucially, the analysis shows that simplifying 'real world' projects requires careful negotiation between how the problem and the specialized scientific knowledge are simplified or else problems ensue for teaching professional reasoning. In short, the chapter shows how teaching engineering is more than simply 'applying' science knowledge to 'real world' problems.

Chapter 10 (Hood and Hao) explores the rich meanings made by body language in face-to-face lectures, drawing on a developing model of paralanguage in SFL (Cléirigh 2011, Hood 2011, Martin and Zappavigna 2019, Ngo *et al.* 2021). Focusing on university lectures in chemistry, Hood and Hao show the extensive means through which technical meaning is distributed across language and body language. In particular, they draw on Hao's model of ideational discourse semantics (Chapter 6, this volume) to detail how the scientific construction of the world in spoken language is regularly coupled with a more 'common-sense' construction in body language, thereby grounding the technical meanings of science. Coming at a time where classes are being increasingly moved online, this chapter offers key insights into what can be lost when we move away from face-to-face teaching.

Chapter 11 (Rose) extends the internationally influential SFL pedagogic programme 'Reading to Learn' into the teaching of mathematics. Rose begins from the straightforward yet significant observation that, when teaching, the symbols of mathematics are typically written down on the board but the procedure of *how to do* the mathematics is spoken aloud. The procedure is thus potentially lost to student at the moment of being taught. To address this, Rose lays out a principled pedagogic programme that makes explicit the procedures involved in solving mathematical problems, exemplified through a secondary school lesson on trigonometry. This involves a series of tasks that progressively build written procedures for doing mathematics and gradually hands over control from teacher to students. As with all aspects of the Reading to Learn programme, this method is developed to ensure that all students have access to mathematical knowledge in ways that are accessible and deliverable in the classroom.

The chapters of this collection will launch new research agendas in understanding knowledge, language and pedagogy in science. They offer major leaps forward in both LCT and SFL, with implications far beyond teaching science.

Notes

1 This book also laid out models of a range of argumentative expository genres, recounts and descriptions, which are more typically found in the humanities and social sciences.
2 For LCT papers, blogs and events, see: www.legitimationcodetheory.com.
3 A fourth dimension, Temporality, is under fundamental redevelopment.

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