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ROUTLEDGE

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THE RELATIONSHIP BETWEEN SPECIALIZED DISCIPLINARY KNOWLEDGE AND ITS APPLICATION IN THE WORLD

A case study in engineering design

Nicky Wolmarans

Introduction

Traditionally, professional education has been about the acquisition of a body of knowledge that graduates are expected to 'apply' in their professional practice after graduation. In this chapter I argue that a model of professions as the application of disciplinary knowledge is inadequate because it fails to take into account the complexity of the 'real world' to which the knowledge is applied. This in turn has led to curriculum design choices that fail to prepare graduates to work dialectically between the complexity of specialized disciplinary knowledge and the complexity of the world in which it is employed.

Engineering provides a rich case study. It is a profession that has positioned itself as a science-based discipline, founded on a canon of well-defined disciplinary subjects. Engineering curricula have tended to focus on the transmission and acquisition of scientific concepts and the relations between concepts, culminating in a final 'capstone' design project. This capstone design project is intended to integrate the specialized disciplinary knowledge acquired throughout the curriculum for application in a single 'real world' project. Most projects are set up to mimic the sorts of projects that engineering graduates are likely to encounter in professional practice (Froyd *et al.* 2012, Harris *et al.* 1994). They are intended to bridge the gap between engineering science and engineering practice. However, many students lack the skills to design when confronted with these design projects for the first time, even when they have successfully completed their engineering science courses (see Kotta 2011 for a detailed study of students' experiences of senior design projects).

Over the last century of engineering education reform (Froyd *et al.* 2012, Grinter 1955, Mann 1918), employers have been calling for improved interpersonal and enabling skills, a strong foundation in the fundamental sciences, and the centrality of design in the curriculum. Recent studies of employer perceptions of graduate engineers report an improvement in, for example, teamwork, communication skills and management compared to the past (J. King 2007, R. King 2008). However, many engineering graduates still appear to be unable to apply scientific knowledge to solve professional problems; as J. King (2007: 7) reports:

> Although industry is generally satisfied with the current quality of graduate engineers it regards the ability to apply theoretical knowledge to real industrial problems as the single most desirable attribute in new recruits. But this ability has become rarer in recent years

In this chapter I address the question of what it means to 'apply theoretical knowledge' to 'real industrial problems' emergent from the complexity of the world. Using engineering design projects in the curriculum as a proxy for real professional problems, I present an analysis of the relationship between material artifacts and the abstract concepts used to analyze and mathematically model them for the purpose of design. The chapter draws on part of a larger PhD study (Wolmarans 2017a) in which 17 engineering design projects located three engineering streams where investigated. Only two of the projects are presented here, both introductory design projects. One is the first project in a sequence of civil engineering projects, the other is the first project in a sequence of structural engineering projects. A comparison of the two projects shows that different ways of simplifying 'real' projects for the purpose of learning have vastly different effects on the nature of the required reasoning.

I bring together concepts from the Semantics and Specialization dimensions of Legitimation Code Theory (Maton 2013, 2014, 2020), because of their capacity when integrated to analyze relationships between objects of knowledge and knowledge of objects. The concept of *semantic gravity* provides a lens to analyze the significance of knowledge of the object of design, while the concept of *semantic density* provides a lens to analyze the complexity of the reasoning. By coding the knowledge requirements of each step in the design thinking process, I am able to show shifts between knowledge of complex things (using the concept of *ontic relations*) and knowledge of complex theoretical concepts (using the concept of *discursive relations*). The analysis contributes to building a more robust model of professional reasoning which has implications for learning. The study provides insight into the limitations of certain types of tasks when they constrain the complexity of thinking about the 'things' being analyzed. In short, privileging specialized knowledge over knowledge of objects effectively distorts the complex dialectical relations involved in professional reasoning. Although the case presented in this chapter is that of engineering, these findings have implications for a range of different professions.

Theoretical framework

The theoretical backdrop to this study begins from Bernstein's distinction (2000) between 'singulars' and 'regions'. He described "singulars as bodies of disciplinary educational knowledge that are strongly bounded from other educational knowledge and from external concerns in the world beyond education. When discussed in broad terms, disciplines such as Physics, Mathematics and History might be described as singulars, each with its own specialized concepts and rules of conceptual relations among concepts. Bernstein described 'regions' as the interface between singulars and the practical concerns of the world – they involve selection of ideas from a range of singulars and their application to a field of practice beyond education. Professions are usually described as regions. This model of knowledge assumes singulars precede regions which in turn project that knowledge onto the world (see Smit 2017 for a detailed critique of this notion of singulars and regions in a study of thermodynamics in science and engineering).

Bernstein's model is useful in that it does recognize a distinction between the structure and organization of specialized disciplinary knowledge (e.g., fluid mechanics) and the structure and organization of knowledge in engineering practice where that knowledge is used in relation to the design of complex systems. However, the model has significant shortcomings. For one thing, it does not address the nature of the relationship between knowledge inside the discipline (abstract fluid mechanics) and knowledge outside the discipline (the design of a slipway for a new yacht basin) – see, for example, Wolmarans (2017b). Based on Bernstein's model of regions, scholars have characterized professional education in terms of mastery of specialized disciplinary knowledge *prior* to its application to problems in the world – the 'word' before the 'world' (Beck 2002, Beck and Young 2005). This model tacitly assumes that if graduates have learned the concepts and legitimate rules of combination among concepts within a disciplinary specialization, then such theoretical knowledge can be unproblematically 'applied' to external problems. It is a model of knowledge that tacitly underpins many engineering programs. But one of the under-developed aspects of this notion of 'regions' is that it leaves us blind to the significance of the contextual detail inherent in professional problems emergent from the world. It fails to take account of the need to translate knowledge structured by the logic of internal conceptual coherence into a logic structured by the external realities of the world. In short, it fails to explore the nature of the external problem itself.

Legitimation Code Theory (LCT) includes a number of conceptual tools that offer a more nuanced way of viewing knowledge practices (Maton 2014). The Semantics dimension of LCT is a particularly attractive analytic tool for investigating professional knowledge in terms of the relations between 'abstract' specialized disciplinary knowledge and 'contextually embedded' professional problems. Semantics centres on exploring the organizing principles underlying practices in terms of *semantic gravity* (SG), which conceptualizes degrees of context-dependence, and *semantic density* (SD), which conceptualizes complexity. Both semantic gravity and semantic density describe a range of relative strengths from stronger to weaker. For example, when SG is weaker, the underlying practices are relatively less dependent on any specific context, while stronger SG means that the underlying practices are relatively more dependent on a specific context. In the case of SD, more complex practices exhibit relatively stronger SD and less complex practices exhibit relatively weaker SD.

For the purposes of this study:

- stronger semantic gravity (SG+) means that making sense of the problem itself and the specialized knowledge recruited to develop a solution are strongly dependent on the specifics of the problem;
- weaker semantic gravity (SG–) suggests that the specialized knowledge is generalizable across multiple contexts;
- stronger semantic density (SD+) indicates projects requiring more complex reasoning; and
- weaker semantic density (SD–) indicates a simpler problem.

SG and SD vary independently of each other and can shift strength through the duration of any activity. SG↑ indicates a process of strengthening semantic gravity, in this case increasing the specificity of a project. SD↓ indicates weakening semantic density, here simplifying either relations among specialized concepts or the aspects of the object of design to be considered.

Semantic codes have been used productively to show the importance of shifting between more abstracted theory (SG–) and more concrete examples (SG+), both in driving cumulative knowledge-building and to identify tacit evaluative criteria. See, for example, Blackie (2014) on Chemistry, Georgiou *et al.* (2014) on Physics, Maton (2013) on Biology and History, and Shay and Steyn (2016) on Design. In terms of recruiting specialized knowledge to solve professional problems, semantic gravity can provide a means of describing the relation between the 'abstract' theoretical knowledge in its academic form and the more 'concrete' problems that emerge from practice. When looking at professional education, semantic density offers a way to look at progression through a curriculum based on increasing levels of complexity, or strengthening semantic density. Shay and Steyn (2016) used semantic codes to analyze a sequence of projects in an introductory design course. Building from their results, they were able to redesign the sequence of tasks into a coherent trajectory of increasing complexity and to identify the link between complexity and 'concreteness' of the project.

I have also used Semantics as an analytical lens. However, semantic density has not yet been used in LCT studies to distinguish between i) the complexity of the object of study or the artifact of design (the thing, what it is and how it works and ii) the complexity of the knowledge recruited to do the analysis (the specialized disciplinary knowledge). In order to make this distinction I draw on the LCT dimension of Specialization, specifically the distinction that Maton (2014) makes between *ontic relations* between knowledge and its objects of study and *discursive relations* between knowledge and other knowledges. For my study, this can be enacted to distinguish between those concepts with which we make sense of things in and of the world (*ontic relations*) and those concepts defined within any specific discipline that conform to disciplinary rules (*discursive relations*). For example, the way in which we understand a bicycle, what it is used for, how to ride it, what it looks like, requires knowledge of a bicycle in terms of its physicality and one's experience of seeing or using a bicycle (ontic relations). Modelling the dynamics of motion, the principles of friction between road and tire, and the strength of the frame requires specialized disciplinary knowledge (discursive relations). In this study I have analytically separated:

- the complexity of the disciplinary knowledge recruited in the task – semantic density of discursive relations or DSD; and
- the complexity of the knowledge of the object of design – semantic density of ontic relations or OSD.

Put simply, I have separately analyzed the complexity of the object (OSD) and the complexity of the specialized knowledge recruited (DSD).

The case study

The data presented in this chapter draws on a PhD study of 'The nature of professional reasoning' (Wolmarans, 2017a). The study was based on an analysis of three sequences of engineering design projects located in two engineering degree programs. Engineering was chosen as the case study because it is a profession that is founded on a well-established scientific knowledge base. The knowledge tends to be more explicit and clearly bounded than in some of the newer professions or those based on social sciences and humanities. The reason for investigating engineering design projects located in a curriculum rather than in practice is twofold. First, the assessment requirements in an educational task require that the design reasoning is elaborated and made more explicit than might be the case in professional practice where professionals may draw more tacitly on their specialized knowledge. Second, because the data was collected in an educational context, engineering design projects were selected because engineering design is seen as the bridging subject between knowledge and practice. Engineering design projects are usually intended to mimic professional engineering projects, making them a reasonable proxy for investigating professional knowledge in action.

Some of the projects analyzed in the broader study include, for example – the design of a culvert to attenuate floodwaters on a particular watercourse; the design of a multistory parking garage; and the specification of the requirements for a power station. Although all the projects in the study were identified as 'design' projects by the lecturers concerned, they did take different forms with different educational objectives and privileged different forms of knowledge. This provided an opportunity to investigate the effect that different ways of simplifying a professional project (recontextualizing choices) have on the nature of the required reasoning.

In this chapter I present a comparison of two of the projects: the design of a bikeshare scheme (U1: Bikeshare scheme) and the analysis of the loading on a structure (S1: Parking structure). Both are introductory projects, the first in a learning sequence of five design projects. Both are intended to mimic aspects of the sorts of projects that professional engineers encounter in their professional practice. However, because the projects are located early in the curriculum, they require substantial simplification in comparison to 'real' engineering projects. The projects need to be constructed so that they are appropriate for students not quite midway through their curriculum, with limited exposure to the range and complexity of the engineering sciences. The projects are further constrained by the limited time available in the curriculum. These two projects were selected because they represent recontextualization based on very different principles of recontextualization. In the case of U1 (Bikeshare scheme) the disciplinary knowledge needed to understand the project requirements was reduced (although it was reintroduced later in the project). In the case of S1 (parking structure) the structure itself was simplified. The analysis is relevant to understanding the consequences of teaching engineering sciences in relation to simplified idealized objects and illustrates some of the unintended consequences of the choices made in terms of how design tasks are simplified.

Data

The data collected for each design project included the design brief and a design solution. The design brief is provided to students at the beginning of the project and lays out the project requirements and task instructions. Briefs tend to identify a problem scenario or client need and describe or refer to a context in which the need or problem arises and in which the proposed design solution must operate. The design solution describes the proposed artifact and documents evidence of the proposed artifact's performance in context. The design solution collected was in the form of either a solution memorandum (a sample solution prepared by the lecturer, a 'model answer') or a student design report. Because design rarely has a 'model answer' and marking rubrics are inadequate to show the details of design reasoning, in most cases student solutions were used as a proxy for a solution memorandum. In these cases, a 'good' student design solution was selected for analysis. The basis of selection was on the grade achieved by the student for the particular project.

Four units of analysis were identified for each project. The design brief typically prescribed an artifact to be designed (*artifact prescribed*) and described or identified a context in which the artifact needed to perform (*context described*). The design solution was analyzed in terms of the resultant artifact proposal (*solution specified*) as well as the process of reasoning required to move from the brief to the final solution (*inferential reasoning*). These four units of analysis – the *artifact prescribed*, the *context described*, the *solution specified,* and the *inferential reasoning* – were coded for each design project. For clarity, the four units of analysis described above are summarized

TABLE 9.1 Units of analysis

Data	*Unit*	*Description of each unit of analysis*
Design Brief	*Artifact prescribed*	Each design brief usually prescribed an artifact to be designed. In some cases, the required artifact may be left to the discretion of the students, emergent from the design purpose.
	Context described	All artifacts function in a context, and the context places requirements and limitations on the design of the artifact.
Design Solution	*Inferential reasoning*	The inferential reasoning refers to the ideas generated, analytical models of potential performance and decisions made during the process of design, from brief to solution.
	Solution specified	At the end of the process of design a final solution artifact is specified. Typically, a design solution would be in the form of a set of technical drawings detailing the artifact proposed as a solution to the design problem.

in Table 9.1. The results of the analysis of each of the units of analysis for the two projects are shown in Table 9.4 (U1: Bikeshare scheme) and Table 9.5 (S1: Parking structure), further below.

The two projects presented, U1 (Bikeshare scheme) and S1 (Parking structure) are both considered to be the first design project in a sequential trajectory of design projects. These projects are compared because they illustrate two significantly different recontextualizing principles evident in the briefs. The parking structure (S1) is recontextualized by simplifying the artifact significantly (OSD↓). The bikeshare scheme (U1) is recontextualized by reducing the disciplinary knowledge required (DSD↓).

Analysis and discussion

LCT Semantics was used to investigate the nature of the reasoning in engineering design projects. Semantic gravity (SG) was used to analyze relations between ideas and the object that they describe, and semantic density (SD) was used to investigate the relation between concepts. In terms of semantic density, it became necessary to distinguish relations between formal theoretical concepts defined within specialized disciplines from more 'everyday' concepts used to make sense of the object of design and the context in which it was intended to operate. This resulted in the distinction between semantic density of discursive relations (DSD) and semantic density of ontic relations (OSD).[1]

The analysis is presented below in three stages. The first stage describes the development and explanation of how semantic gravity and semantic density were

TABLE 9.2 Semantic gravity categories of analysis

SG+/–	*Code description*	*Examples*
Generic or idealized, described in terms imposed from a body of disciplinary knowledge.		
SG– –	Meaning resides in **general** laws or concepts that **transcend** contexts; it does not require a concrete reference to make sense.	S1 solution: A compressive force which is transferable across all contexts and is applicable to all bodies as a result of gravity.
SG–	Meaning is **imposed** from a disciplinary body of conceptually coherent knowledge, but the general law/s or concept/s are **specialized** for application to an object or class of object.	S1 artifact: The structure is idealized but also unrealistic and impractical. It is designed to elicit analytic techniques rather than to perform a material functional.
Specific and detailed, described in terms emergent from the context		
SG+	Meaning relates to (originates in) a **type** of object or system; it refers to real objects, but abstracted from a specific, unique instance to a **class/type** of object.	U1 artifact: A type of system; the brief does not prescribe the specifics of any particular system.
SG++	Meaning relates directly to a **specific instantiation** of an object**,** described in **rich detail** specific to a **unique** case/situation.	U1 context: A specific campus accessible to students as part of the design project. Familiarity with the specifics of the campus is required.

operationalized in this study. The tables summarizing the categories that were used to analyze the data (Table 9.2 and 9.3) make reference to examples from the data. The examples are presented in the second stage where analysis of the two projects is compared. The process of reasoning required to develop a solution to the task is further elaborated in the third stage, where each step in reasoning is linked in a chain or network of inferential steps.

Operationalizing semantic gravity and semantic density

The analytical categories used for semantic gravity are shown in Table 9.2. At the first level stronger semantic gravity is distinguished from weaker semantic gravity based on whether meaning emerges from an understanding of the contextual or material detail (SG++ and SG+) or appears to be imposed from a specialized body of knowledge (SG– – and SG–). Within stronger semantic gravity I differentiate between *specific* or unique artifacts or contexts (SG++) and somewhat more general *types* or classes of artifacts or contexts (SG+). Within weaker semantic gravity I distinguish between *generalized* laws or principles that transcend contexts (SG– –) and generalized theories *specialized* and imposed on the artifact or context in order to describe it (SG–).

TABLE 9.3 Semantic density categories of analysis

SD+/–	*Description*	*Examples*
	Integrated or condensed into a coherent whole	
SD++	Multiple **interdependent** concepts/components integrated into a coherent whole. Theoretical antecedents/ causal interdependencies are **embedded** and not identified explicitly	DSD++: As entry projects neither required students to identify and select relevant disciplines from others. OSD++ U1 context: Students are referred to the UCT campus; a complex context with emergent characteristics.
SD+	Multiple **interdependent** concepts/components integrated into a coherent whole. However, relevant disciplines/concepts/objects are explicitly **identified** while retaining **simultaneous** interdependencies	DSD+ S1 inference: The calculations integrate geometric considerations, mathematical techniques and structural analysis. OSD+ U1 inferences: Simultaneous consideration of surveyed route, gradients, chosen bicycles, inexpert users, and shared user spaces.
	Separated or elaborated into constituent parts	
SD–	Relevant concepts/components are identified and **separated** into a **linear sequence** of prescribed relations.	DSD– S1 artifact: The structure is designed to demonstrate a sequence of analytical techniques at the expense of functionality. OSD– U1 solution: The solution is presented as a sequence of features listed in the report.
SD– –	A **single** concept/component is identified as relevant and is **isolated** and **dislocated** from its disciplinary/contextual relations.	DSD– – U1 context: Located in a surveying course identifies surveying knowledge as the only relevant discipline. OSD– – S1 inference: Each structural element is analyzed in isolation from the others.
SD_0	No specialized concepts or knowledge of the object are required.	DSD_0 U1 artifact: Students are referred to Wikipedia for a description of a bikeshare scheme. OSD_0 S1 context: The structure is stripped of interaction with a real context.

The analytical categories used for semantic density are shown in Table 9.3. Ontic semantic density (OSD) here refers to concepts used to make sense of the 'things' of the design, where coherence among concepts tends to be held together by the contextual details of the material artifacts – what they are and how they work. Discursive semantic density (DSD) here refers to formal concepts defined within a specialized body of knowledge and the formal conceptually coherent relations among them. As described previously, OSD requires knowledge of the physicality and experience of an objects, while DSD requires knowledge of the formal specialized knowledge used to analyze the object.

The strength of semantic density was categorized in relation to the level of detail, number of concepts and number of relations between the concepts. It relates to the nature of those conceptual relations needed to complete the design task. Although OSD was differentiated from DSD, the principles that define the coding categories are the same. In both cases stronger semantic density (SD++ or SD+) implies integration as the main principle of categorization. Weaker semantic density (SD– – or SD–) implies separation or elaboration as the main principle of categorization.

Within stronger semantic density, SD++ means that integrated interdependencies are embedded but not necessarily obvious. For example, students may need to identify appropriate disciplinary knowledge or concepts within a discipline without being given direction, or students may need to distinguish between those aspects of an artifact which are relevant to the design from those that are incidental to the task. SD+ indicates that the brief or instructions are given in such a way that the relevant components or concepts have been identified for students, although the parts retain necessary simultaneous interdependence. For example, the brief may instruct students to design a gearbox, including selecting a motor, bearings and power transmission elements and designing the shaft. This identifies separate components for students, but each component interacts interdependently with the others. All design decisions interact with other design decisions.

Within weaker semantic density, SD– means that each component or concept has been identified for students and retain a sequential relation. In other words, each relevant concept is identified and one concept links sequentially to the next concept. SD– – indicates that a relevant component or concept has been identified for students but separated to the point of dislocation from other components or concepts. For example, students may need to size a bearing dislocated from other machine components or students may be required to do a single calculation dislocated from the complex conceptual network of meaning defined within a discipline.

Comparative analysis of the two introductory design projects

The two projects compared in this chapter both represent design projects at the beginning of a sequence of design projects. At this point in the curriculum students have little to no experience in design and have limited proficiency in the engineering sciences but are expected to be relatively proficient in mathematics and the basic sciences. Thus, design projects need to be significantly recontextualized in comparison to 'real' professional projects, to align with the expertise that students are expected to bring. The first design project in the 'civils' stream in civil engineering required students to design a bikeshare scheme for the University of Cape Town Campus (U1: Bikeshare scheme). The project was a two-week block course in surveying. The project illustrates recontextualization that leaves the contextual and material details (ontic relations) intact, while reducing the disciplinary knowledge (discursive relations) to a single discipline with a sequence of specialized procedures prescribed. The first design project in the 'structures' stream in civil engineering required students to complete a loading analysis of a generic parking structure (S1: Parking structure). The project was integrated into the first structural engineering course and ran parallel to the engineering science content taught in the course. The project illustrates recontextualization based on stripping the contextual and material details (ontic relations) in order to develop specialized conceptual relations (discursive relations).

The analysis of the projects first compares the four units of analysis for each project, namely the *artifact prescribed*, the *context described* in the brief and the *solution specified* and the *inferential reasoning* required to develop the solution. The analysis illustrates the effect of recontextualizing choices on the complexity of understanding required to engage in the task. The categorization of the *inferential reasoning* is elaborated in the second analytical section. It shows the inferential chains of reasoning required of students as they develop an adequate design solution proposal. The analysis of the detailed *inferential reasoning* is particularly interesting in that it shows how significant stronger semantic density of ontic relations (OSD) are to the development of professional reasoning.

U1: Bikeshare scheme

The *artifact prescribed* in the brief was a 'bikeshare' scheme, a type of system (SG+). Initially the artifact can be understood in 'common sense' ways without recourse to specialized disciplinary concepts (DSD_o); students are referred to Wikipedia for a generic description of a bikeshare scheme. The information provided by Wikipedia functions to assist students to identify the relevant elements of the system and recognize how they interact as a system (OSD+).

The *context described* in this project is integral to the design. Rather than describing the context, students are referred to the UCT campus in its current form, including the terrain and usage: a congested campus with limited parking and narrow pathways shared by motor vehicles, busses and pedestrians. The climate is dry hot summers with strong winds and cool wet winters. The campus is built on the slope of a mountain and has many staircases and steep inclines. These details (SG++) are not specified in the brief and it is expected that the students will draw on their own experiences of the campus in the design. The design brief specifically identifies the campus and does make reference to some of the aspects of the campus context that might be considered, such as drawing attention to the importance of surrounding buildings and their usage to determine potential demand; potential interaction with the student bus service; and implied relations to existing roads for access. However, much of the detail is left to students to elaborate from their own everyday and embedded experience of the campus. Students need to either identify as significant or discard as irrelevant to the design details from their experience. The context is thus richly detailed and complex but without much guidance in terms of what to consider and what to ignore (OSD++). Initially students are able to engage with and make sense of the context without specialized disciplinary knowledge, although the location of the course in a surveying course does imply the importance of a single discipline over others that may be relevant to this project (DSD– –).

The *solution specified* has been analyzed in two parts because of the differences in the nature of the parts. The description bikeshare system (U1A: Bikeshare description) included bicycle selection, safety equipment, exchange logistics, storage and maintenance plans specific to this particular context (SG++). It was descriptive in nature and retained its unspecialized format (DSD– –). Each element was identified and described sequentially (OSD–) without much evidence of simultaneous interferences evident in the specification of the solution.

However, the real focus of the project was on the survey of the route and the modifications required to accommodate its purpose (U1B: Bikeshare route). This part of the solution was presented in the form of a digital elevation model (DEM), a specialized representation of a particular terrain (SG++). A number of vertical profiles at significant points along the route needed to be modified. Modifications were required along the route to accommodate, for example, inexpert users and interaction between multiple modes of transport. Although the process of developing the design (*inferential reasoning*) required networks of simultaneous considerations, the presentation of the solution is simplified. Each part of the map can be read as a sequence of positions along a contour map, and a sequence of vertical profiles (DSD–). And the route is a significant simplification of the campus, with each modification understood in relation to the terrain in one sense and the users in another (OSD–).

The *inferential reasoning* on the other hand required simultaneous consideration of the contextual details of the route in relation to specialized surveying knowledge. The network of inferences involved a range of different strengths of both OSD and DSD. Although a sequence of steps for the survey was provided in the brief, each step involved interrelations between measurements with specialized equipment, conversion into specialized surveying representations using multiple mathematical relations, and the separation of vertical and horizontal interactions and conversion into a map (DSD+). Once identified, the route itself could be considered sequentially, but at each point in terms of interactions between terrain and a range of users, including expected expertise of cyclists, interaction between different modes of users (cyclists pedestrians and motorized transport) (OSD+). The network of simultaneous reasoning shown in Figure 9.3 illustrates the nature of OSD+, DSD+. Table 9.4 is a summary of the analysis above and is illustrated in Figure 9.2.

S1: Parking structure

The *artifact prescribed* is a generic structure, stripped of all functional elements (ramps, lifts, parking and vehicle flow arrangements). Figure 9.1 shows the structure reduced to a collection of columns, beams and slabs configured in such a way as to offer a range of different analytical challenges. That is, disciplinary analytical requirements are imposed on the structure at the expense of functionality (SG–). As a result, each structural element can be treated independently of the others (OSD– –). As with

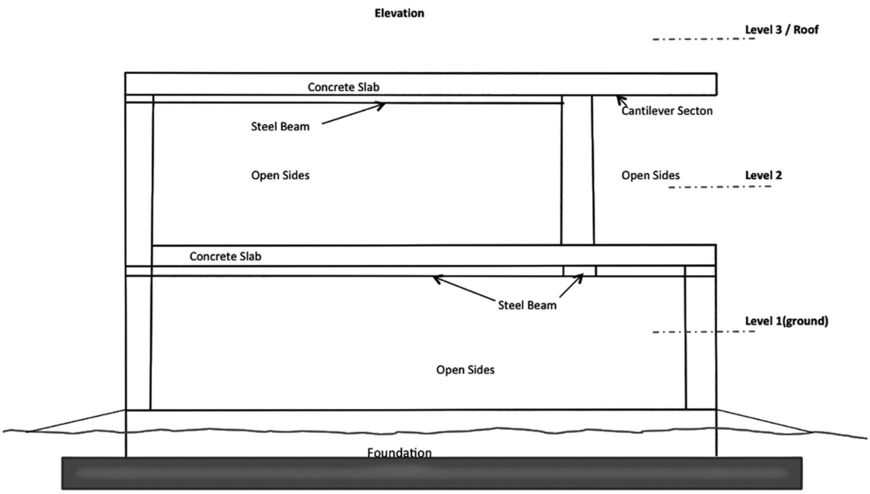

FIGURE 9.1 Idealized parking structure (S1)

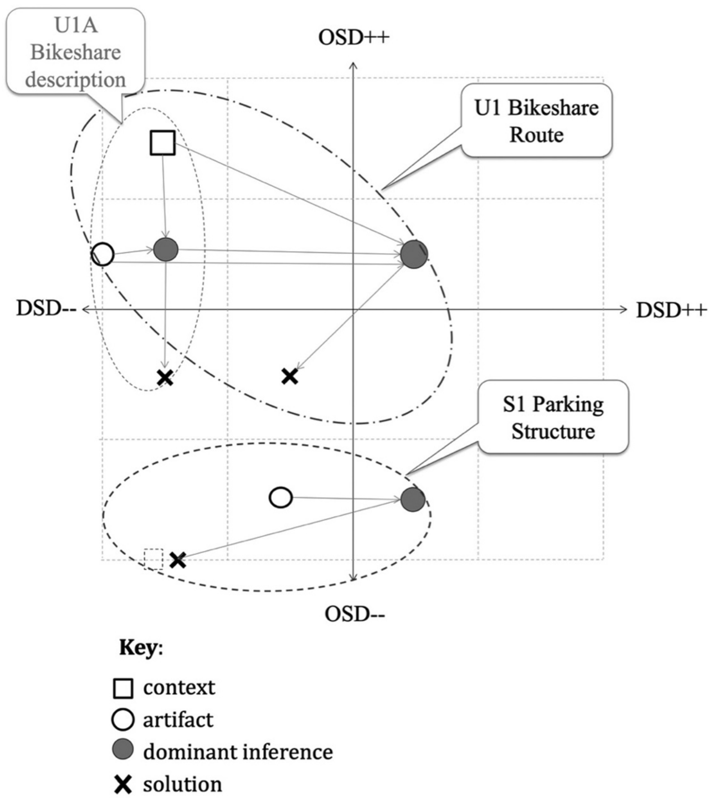

FIGURE 9.2 Effect of recontextualization by weakening OSD (S1) or DSD (U1)

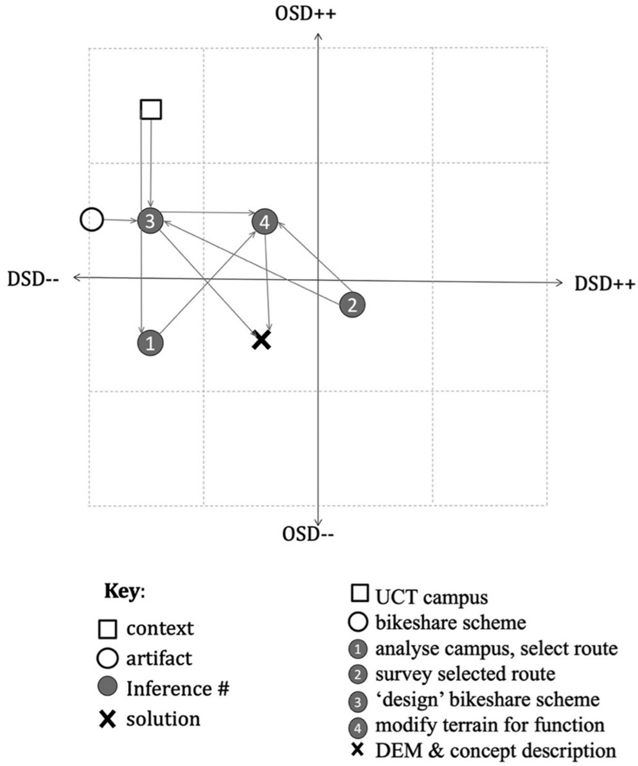

FIGURE 9.3 Inferential reasoning: U1 (Bikeshare scheme)

U1 (Bikeshare scheme) the project is located in a disciplinary course in structural analysis, signaling structural analysis as the only significant discipline. However, the description of the structure does include a list of symbolic markers used to link the elements through a sequence of disciplinary calculations (DSD–).

The *context* in which the structure operates is stripped from the project to the point of being completely general (SG– –) and replaced by a single symbolic representation of a 'live load' (variable load imposed under operation, specified for typical loading types). Even this level of understanding of a live load is not required to complete the task (OSD_o). The parking load is quantified as a uniformly distributed load given in the brief as $4kN/m^2$ (DSD– –).

The *solution specified* was in the form of four compressive forces operating at the base of each of the four bottom columns. The form of the solution is completely transferable across all contexts, and in an abstract sense is applicable to all bodies in that all bodies on earth interact with a surface by a compressive force at their base as a result of gravity (SG– –). As with the *context description* given in the brief, the answer is a single symbolic term dislocated from its relation to other terms disciplinary terms (DSD– –) and stripped of any interaction in the world (OSD_o). Students are able to present the answer without engaging at all with what it means in the world.

TABLE 9.4 Summary of analysis U1: Bikeshare scheme

Unit of analysis	*Semantic code*
Artifact prescribed	Bikeshare Scheme: SG+, OSD+, DSD_0
Context described	University campus: SG++, OSD++, DSD– –
Solution specified	Bikeshare description: SG++, OSD–, DSD– –
	Bikeshare Route (DEM): SG++, OSD–, DSD–
Inferential reasoning	Bikeshare description: SG++, OSD+, DSD– –
(dominant mode)	Bikeshare Route (DEM): SG++, OSD+, DSD+

TABLE 9.5 Summary of analysis S1: Parking structure

Unit of analysis	*Semantic code*
Artifact prescribed	Generic structure: SG–, OSD– –, DSD–
Context described	Uniform distributed load: SG– –, OSD_0, DSD– –
Solution specified	Discrete compressive load: SG--, OSD_0, DSD– –
Inferential reasoning (dominant mode)	Prescribed sequence of procedural calculations: SG–, OSD– –, DSD+

The details of the analysis of the *inferential reasoning* are shown in Figure 9.4. The reasoning remains discursive, imposed on the structure for the purpose of structural analysis (SG–). Each element is considered sequentially but can be considered independently of the other elements (OSD– –), linked only through a sequence of calculations prescribed in the brief. Although the inferential steps are a prescribed sequence of calculations, each calculation does integrate a number of structural engineering principles that work together interdependently (DSD+).

The analysis summarized in Tables 9.4 and 9.5 is illustrated in Figure 9.2. on a plane showing semantic density (OSD and DSD). There are three different patterns of reasoning evident. The bikeshare description (U1A) shows the design of the overall bikeshare scheme: bicycle selection, storage and exchange, the position of bike shelters for storage with consideration of access for maintenance, and the prescription of required safety gear. The bikeshare route (U1B) shows the disciplinary component of the design, the survey and generation of the DEM of the proposed modifications to the route taking into account the bikeshare description (U1A), users and terrain. The parking structure (S1) shows the loading analysis on the structure.

Discussion of the effects of recontextualizing choices in the design brief

The basis of recontextualization of the brief in U1 (Bikeshare scheme) is the weakening of DSD: both context and artifact can be adequately understood without requiring any specialized disciplinary knowledge. On the other hand, students need

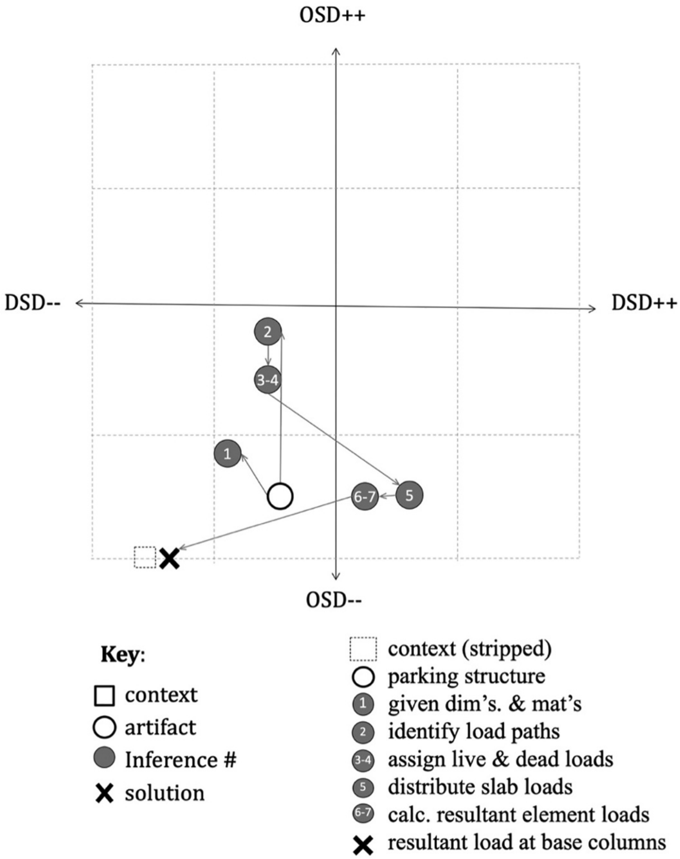

FIGURE 9.4 Inferential reasoning: S1 (Parking structure)

to construct considerable understanding of the context and artifact to begin the design task: the strength of OSD is retained. By comparison, the basis of recontextualization of the brief in S1 (Parking structure) is the weakening of ontic relations OSD: both context and artifact can be adequately understood without engaging meaningfully with the context or the functionality of the structure. Here, the structure is constructed such that students need to engage with a number of different analytical approaches defined within the specialization of structural engineering: the strength of discursive relations DSD is retained.

Both principles of recontextualization have consequences. In the case of the bikeshare description (U1A), students are able to develop a solution based solely on common sense knowledge and experience without recourse to disciplinary knowledge. The science of logistics of the scheme, the structural analysis of the associated storage structures, formal principles of usage analysis were not required in the recontextualized project. Projects of this nature do *not* help students to learn to reason using specialized disciplinary knowledge in relation to the complex reality of the world. Instead students are able to develop an adequate solution based solely on common sense. However, by locating the project in a surveying course and providing a requirement to survey the route and propose modifications in terms of gradient changes and vertical elevation points for the bikeshare route design (U1B), disciplinary knowledge was introduced into the project and students were required to engage simultaneously with both with the complexity of the world (stronger OSD) and with disciplinary knowledge (stronger DSD).

In contrast, the recontextualized brief presented in S1 forces students to engage with structural engineering principles and procedures (stronger DSD), but in this case without any significant engagement with the complexity of the world (weaker OSD). Again, projects of this nature do *not* help students to learn to reason using specialized disciplinary knowledge in relation to the complex reality of the world. In this case students are able to develop an adequate solution based solely on disciplinary knowledge and procedures, without engaging with the complexity of a real object functioning in context.

The analysis of *inferential relations* that was described above was determined by the nature of the relations between concepts through the process of design. The details of the analysis of the inferential relations is elaborated in the section that follows. At this point suffice to say that the categorization of the inferential relations shown in Figure 9.2 is based on the pattern of reasoning between context, artifact and each step in the process of design from brief to final solution. In the case of bikeshare route design (U1B) the strength of the ontic relations of the artifact and context were retained, and certain discursive relations were required. Each step in the prescribed sequence of tasks then drew interdependently on the artifact, context and prior steps. In the case of the parking structure loading analysis (S1), the ontic relations were stripped from the context and weakened for the artifact. Although the discursive relations remained strong, the prescribed inferential steps became effectively independent of artifact and context, resulting in a linear sequence of reasoning.

In summary, weakening the semantic density of ontic relations risks dislocating the reasoning from the complexity of the world, resulting in a linear sequence of reasoning. Retaining the complexity of ontic relations without introducing a disciplinary knowledge component risks severing the links to professional knowledge. This is particularly a risk early in the curriculum when students have limited proficiency with specialized knowledge. In order to develop the skills needed to reason between the world (ontic relations) and specialized disciplinary knowledge (discursive relations), it is critical to retain or introduce both ontic and discursive components in the requirements of the design project. The design of the bikeshare route (U1B) provides one example of how this might be done.

The effect of recontextualizing choices on inferential reasoning

This section elaborates the categorization of the inferential relations presented above. The analysis is based on a list of sequential steps provided in an addendum to each brief. Each step was analyzed in terms of its own relative complexity and the relations to other steps in the process. Figures 9.3 and 9.4 show a comparison between the steps involved in the design of the bikeshare route (U1B) and the analysis of the parking structure (S1), respectively. What is immediately evident is the difference in the patterns of reasoning. Figure 9.3 (U1B) shows a network of inferences required in the development of a solution. Figure 9.4 (S1) shows a chain of inferences.

S1 (Parking structure), shows how weakening OSD to the point of dislocation resulted in a single input point (○) at the start of the chain of reasoning. With the context (□) stripped, it plays no role in the reasoning. What results is a linear sequence of potentially procedural calculations as the load is calculated at each level. With the retention of stronger OSD in U1B (Bikeshare route), both the artifact (○) and the context (□) are relevant to the development of the solution (✕). The interdependence between steps is retained and the resultant inferences resemble a network rather than a chain. For example, Step 4 in U1B requires proposals for modifying the terrain of the route. This draws on the interaction between artifact and context: the analysis of the campus (Step 1), the survey of the selected route (Step 2), and issues emergent from the description of the bikeshare scheme (Step 3). Decisions such as modification of the maximum operational gradient for inexpert/casual cyclists or the introduction of wider lanes to accommodate multimodal transport rely on a network of interdependent reasoning.

A comparison of the analysis of each project suggests that when ontic relations are stripped – as in S1 (Parking structure) – the resulting reasoning tends to be linear. On the other hand, despite stripping the discursive relations in the brief for U1 (Bikeshare scheme), the retention of the complexity of the ontic relations resulted in a more complex network of reasoning. However, without prescribing requirements for using disciplinary knowledge – surveying knowledge and procedures in the case of U1B (Bikeshare route) – the risk is that the semantic density of discursive relations will remain weak, as illustrated in the bikeshare description (U1A).

The influence of semantic gravity

One final point to make refers to the relationship between the semantic density of ontic relations (OSD) and semantic gravity (SG). The complexity of the ontic relations in U1 (Bikeshare scheme) is retained (OSD+), while in S1 (Parking structure) the ontic relations have been simplified to the point of dislocation (OSD– –) or striped of relevance completely (OSD_o). This tends to correspond with the strength of semantic gravity. The specificity of a context or artifact (SG↑) depends on the level of detail of ontic relations (OSD↑). On the other hand, as ontic detail is stripped (OSD↓) the object becomes more generic (SG↓). This suggests that retaining stronger OSD requires the brief to refer to more specific contexts and artifacts. But that leaves the question of redundancy of OSD. If the strength of OSD corresponds with the strength of SG, is it not redundant to introduce OSD? With reference to the analysis of the *inferential reasoning* in U1B (Bikeshare route) presented in Figure 9.3, the diagram shows a wide range of OSD, however the reasoning always relates to the specific solution of a specific campus (SG++). While there is some correspondence between OSD and SG, it is not inevitable. Even if a specific object is referenced (SG++) that object may be more or less complex in its own right (OSD can vary between OSD++ through OSD– – through a design). The context (university campus) referred to in the case of U1 (Bikeshare scheme) is extremely complex (OSD++), but the analysis of a particular slope on the selected route is significantly simplified (OSD–). Both relate to a specific context or part of the context (SG++).

Concluding remarks

Real artifacts and real contexts are extremely complex in their contextually embedded state. Making sense of them and simplifying them in order to make design decisions and to predict performance requires making sense of the contextual details, both in terms of unspecialized 'everyday' familiarity, and informed by disciplinary insights. Projects or 'problems' encountered in the 'real world' are specific, contextually embedded and emergent. In their emergent form they would typically be coded SG++, OSD++, DSD_o. While many 'problems' encountered in the world can be resolved without recourse to specialized knowledge, those projects or problems that fall into the preserve of any particular profession do assume the recruitment of the specialized knowledge associated with that profession. Those projects require the professional to strengthen the semantic density of discursive relations significantly (DSD↑) as they identify appropriate theoretical principles from the canon of professional knowledge (DSD++). In order to theoretically model any potential solution, the material complexity of the emergent problem (ontic relations) needs to be simplified; a process of weakening the semantic density of ontic relations (OSD↓) by identifying relevant aspects of the problem and discarding those that are not relevant. But this process is not independent of discursive relations; OSD↓ is likely to be informed by introducing principled insights (discursive relations), which involves DSD↑.

Students learning to become engineers or other professionals need to learn to identify and recruit appropriate specialized disciplinary knowledge to solve professional problems. Students should not be expected to develop this expertise without an explicit introduction, at an appropriate level of complexity. This is especially so early in the curriculum before students become proficient in multiple disciplines, or even have much familiarity with the objects of their profession (what they are and how they work). It is therefore necessary to simplify those projects intended to mimic professional projects to an appropriate level of complexity for any particular point in a learning trajectory. The two projects I have contrasted in this chapter appear at the start of the design learning trajectory and so required significant recontextualization. The analysis shows the way in which the *artifact prescription* and *context description* are recontextualized in the design brief affects the relationship between 'concrete' object and 'abstract' theory, modifying the inherently dialectical relation between them.

The argument I am making is that when the semantic density of ontic relations (OSD) remains stronger, the required reasoning is more complex. It is likely to result in a simultaneous network of inferences between ontic relations and discursive relations rather than a sequential chain of inferences. Of course, if the discursive relations are not relevant, the reasoning is also simplified, but in a different way, the reasoning never requires the semantic density of discursive relations (DSD) to be strengthened. The suggestion is that professional reasoning requires dialectical reasoning between ontic relations and discursive relations. If ontic relations are stripped then the reasoning becomes more procedural, while if discursive relations are stripped the range of semantic density is reduced, and the significance of specialized disciplinary knowledge is compromised.

I have not suggested any prescription of how one 'should' simplify design projects; there are many ways to do that. But if one is aware of the potential consequences of the recontextualization choices made, then one can be more intentional about designing coherent learning trajectories. In typical engineering curricula, based on learning decontextualized sciences, there is a tendency to weaken OSD to the point of dislocation. Unless one takes seriously the complexity inherent in objects in the world and the effect that they have on the complexity of reasoning required to analyze them we will continue to be surprised when students cannot 'just' apply theory to the sorts of complex, contextually emergent problems that professionals encounter in practice.

In addition to insights into the empirical challenge of educating professionals, this study offers insights for building a better model of professional knowledge. Models of professions based on what Bernstein (2000) called 'regions' argue that specialized knowledge should be taught first and can then be 'applied' to external problems. But regions face both internally to specialized bodies of knowledge and externally to their application in fields of professional practice. This suggests that both internal relations of coherence (conceptual – discursive relations) and external relations of coherence (contextual – ontic relations) need to be held simultaneously. There is a dialectical relationship between the internally defined disciplinary knowledge and the externally emergent problem in the world. It is thus not merely an application of specialized knowledge onto an emergent problem. Professional reasoning shifts continuously between the internal specialized knowledge *and* the external concerns of the problem.

This study contributes to understanding 'regions', an underdeveloped concept in code theory, and shows how LCT Semantics can provide a lens into the external objects of analysis. Moreover, the categorization framework offers an analytical language that may be useful to other professional education research and development studies. As education moves in the direction of regionalization and education moves towards a focus on application of knowledge in the world, the complexity of the world needs to be taken into account. Otherwise we run the risk of sliding into issues of personal attributes and generic skills. We risk losing the power of specialized disciplinary knowledge because very few students learn to use specialized knowledge in the contextually complex situations that are the workplace.

Note

1 For an earlier version of the analytical distinction between ontic relations and discursive relations, see Wolmarans (2014).

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