Exploring professional engineers' knowings-in-practice in an emerging industry: An Actor-Network Theory approach

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Copyright and Declaration

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Declaration

I declare that I have composed this thesis myself and that it embodies the results of my own research. Where appropriate, I have acknowledged the nature and extent of work carried out in collaboration with others included in the thesis.

Signed,

Jennifer Scoles

Acknowledgements

Although the cover page of this thesis carries my name, the creation of this work is far from an individual accomplishment. It is, instead, the effect of a powerful actor-network. Many actors have gathered together and connected over the last six years to assemble this thesis. The strength of these connections has been phenomenal, resisting a variety of external forces threatening to destabilise the completion of this thesis. Making visible these key actors is the least I can do to express my gratitude.

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Abstract

This thesis presents a sociomaterial perspective on how everyday engineering work practices are being changed by the complexities and tensions prevalent in emerging industries. Presenting the wind energy industry, in the renewable energy sector, as a case, this study contends that current engineering education practices are not adequately preparing and supporting students and professionals for work in highly volatile, precarious industries. This study pays close attention to how engineers enact competent knowing and learning strategies to respond to, and navigate, these complexities and tensions.

Traditional engineering education practices tend to frame engineering work as a bounded, stable, rational, and technical endeavor, where knowledge is regarded as a commodity to be acquired. Rather than treating professional knowledge as an independent reality of the engineering field, this thesis argues that education practices can be informed by making visible mundane and taken-for-granted aspects of engineers' everyday work, and reconfiguring conceptualisations of engineering knowledge as situated, collective, on-going, and materially-mediated performances. To do so, this study draws on concepts of knowing-in-practice and Actor-Network Theory, which position engineering work as heterogeneous assemblages of social and material relations.

An ethnographic methodology afforded the tracing of social and material relations between 13 participating engineers and the objects of their practice in a wind energy organisation located in a Scottish city. Following six months of observations and interviews, three activities that generated high intensity in the engineers' everyday work were analysed: securing a signature on a contract, the unfolding of a specific organising process, and implementing a new technology. Analysis revealed four tensions that needed to be constantly negotiated, which included balancing: commercial objectives and client needs with traditional engineering concerns; standardising practices with innovating practices; acceptable practice with allowable deviation; and visibility with invisibility.

Emerging from the findings were clear indications that the multiple knowings-in-practice enacted to negotiate these tensions were interdependent, yet partial, fluid and multiple, sociomaterial performances. This thesis offers recommendations for education practices based on these findings, which challenge dominant representational and individualistic conceptualisations of engineering education and workplace learning. Furthermore, a ‘dynamic stability’ sensibility is offered as a pedagogical approach that encourages attunement to the performance of fluid and informal infrastructuring practices, which tolerate volatility and high-change in work practices.

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AR: Agreed Requirements

BDM: Business Development Manager

FIDIC: Fédération Internationale Des Ingénieurs-Conseils (International Federation of Consulting Engineer)

HR: Human Resources

MD: Managing Director

NCR: Non-Conformity Report

PCE: Project Contract Evaluation

PM: Project Manager

PR: Public Relations

QRI: A formula representing risk: Repetitiveness x Cost x Impact

RE: Renewable Energy

ROC: Renewables Obligation Certificates

SGP: Stage Gate Process

Chapter 1: Emerging industries, changing professional work and educational struggles

In recent years, the global challenges to meet pressing social, technical, economic and political needs have shifted the emphasis in trade and commerce towards prioritising the growth of emerging industries (Engineering UK, 2016; HM Government, 2009; Tansel, 2008; UK Commission for Employment and Skills (UKCES), 2012). There is a high demand for skilled professionals to work in jobs created by these industries to address issues of sustainability, climate change and the transition to a low-carbon economy (Energy & Utility Skills, 2014; International Labour Office (ILO), 2011; UKCES, 2012). In particular, engineers are being positioned as crucial actors to ensure the successful future of these industries, for example, in the renewable energy sector (Engineering UK, 2016).

However, numerous reports have raised concerns that engineers remain inadequately prepared to address the complex demands of everyday work in renewable energy industries (e.g., Rowe, 2013; RenewableUK, 2013a; Ritchet, 2016). Current public policy firmly places education as being responsible for remedying the perceived lack of skills and preparation in response to industry demands (Skills Development Scotland (SDS), 2015; Fitch Roy, 2013; UKCES, 2012). For example, TPWind's report (Fitch Roy, 2013, p. 14) cited that employers most frequently attributed the lack of competent practitioners in engineering to "a mismatch between the education system and new technologies and industries, perhaps due to links with academia not being strong enough". Consequently, there is a widespread call for the training and 'upskilling' of individual practitioners to close, or 'plug' this 'skills gap' (RenewableUK, 2013a, SDS, 2015, Siemens, 2014).

Yet, despite the upsurge in skills training, and increased access to Higher Education programmes and apprenticeships, the dearth of competent practitioners persists (RenewableUK, 2013b). For those concerned with professional education, a pedagogical issue arises: how can educational practices better prepare and support students and practitioners for work in emerging industries, such as renewable energy industries? I take this broad question as a point of departure for my thesis.

I propose that current education approaches to ‘plugging’ the ‘skills gap’ may be limiting, as they tend to focus on the linear, individual preparedness of any given practitioner. In doing so, issues of work are separated from issues of knowledge and learning (Mulcahy, 2011; Zukas & Kilminster, 2014), and complexities and materialities of everyday work practices remain unaccounted for in education practices (Fenwick, 2014).

In this thesis, I contend that a wider view of this issue can be obtained when educational practices, and issues of knowledge and learning, are framed as being entangled with, and mutually dependent upon, the social and material relations unfolding in professional work. For example, a closer look at engineers’ everyday work activities reveals that engineering practices in emerging industries are being shaped and changed daily by the introduction of new technologies (Kaplan & Vinck, 2014), different ways of organising (Ekstedt, 2009), and rapidly shifting governmental agendas, which often leave professionals “frantically struggling to adapt to knee-jerk policy changes” (Siemens, 2014, p. 22). The recursive interplay between these different forces generates complex knowledge demands, which are difficult to foreground, anticipate, and negotiate.

In this thesis, I am concerned with the everyday work practices of engineers who are working in the emerging industry of wind energy, situated within the renewable energy sector, in Scotland. I purposefully use the adjective ‘everyday’ to signify that both their routine and improvised work activities were often so mundane or taken-for-granted that they could be considered unremarkable. I focus on educational practices that are situated in pre-service education, such as Further Education and Higher Education (HE) institutions, and those that are performed in workplace settings, for example, with professional associations, HR departments, the collective professionals, and external training bodies. I define ‘education’ as “intentional processes for producing knowledge, practices and subjectivity that involve purpose and pedagogy” (Fenwick & Edwards, 2010, p. ix).

In considering the interdependency of engineers' work and education practices, I contend that educators need to look beyond trying to predict what specific skills and techniques should be taught to students and practitioners, towards supporting ways of negotiating and navigating complex, conflicting, and uncertain demands and problems that emerge in everyday work. To do so, I argue that this thesis offers new directions for how education practices could be assembled, and alternative vocabularies for re-conceptualising issues of knowing, learning and work.

To position this argument in the context of this thesis, I propose three concerns that must be considered concurrently: the shifting intellectual landscape of engineering education; the wider sociological issues of changing professional work; and the need to reconceptualise workplace learning perspectives.

A shifting intellectual landscape

Firstly, scholars have argued that engineering education is currently problematic, and that actual and potential tensions exist between engineering education practices and the realities of current work practices (Johri, 2009; Jørgensen & Brodersen, 2016; Nair, Patil, & Mertova, 2009; Sheppard, Macatangay, Colby, & Sullivan, 2009; Trevelyan, 2014). Trevelyan (2014) highlights that traditional, dominant models of engineering education treat engineering work as a technical, rational, purely scientific, and bounded endeavour. Yet researchers studying engineers' everyday practice have shown that engineering work is in fact highly social, ambiguous, complex and uncertain, and is influenced by local, social, economic, political and natural factors (e.g., Bucciarelli, 1994; Trevelyan, 2014; Vincenti, 1990; Vinck, 2003).

Responding to concerns that the investigation of the everyday work done by engineers in the field has been extremely limited (Stevens, Johri, & O'Connor, 2014; Trevelyan, 2014), recent edited publications (Jørgensen & Brodersen, 2016; Williams, Figueiredo, & Trevelyan, 2014) have specifically engaged in a 'practice turn' to study engineering work and education. This mirrors a wider turn to practice that has emerged over the last two decades in organisational studies concerned with workplace learning (e.g., Nicolini, Gherardi, & Yanow, 2003;

Orlikowsi, 2002). Practice-based studies are distinct approaches that theorise knowing and learning as “situated in the on-going systems of action, as relational, mediated by artefacts, and always rooted in a context of interaction” (Nicolini et al., 2003, p. 3). Stevens et al. (2014) argue that it is only by understanding the organisation of professional engineering work and its effects on society, individuals, and nature that efforts to reconceptualise professional engineering work and education from the outside are likely to be successful. Therefore, in this thesis, I argue that looking to practice-based approaches may help address proposed tensions and disconnections between engineering education and work.

Unresolvable tensions for professionals

Wider sociological issues are also creating unresolvable tensions that characterise professionals’ everyday work. This leads to the second concern: that the very nature of professional knowledge and practice is changing due to globalised work demands (Evetts, 2011; Fenwick, Nerland, & Jensen, 2012a; Green, 2009; Jensen, Lahn, & Nerland, 2012). Issues of accountability, rapidly proliferating and contested knowledge sources, and new ways of organising are creating increasingly contradictory and complex spaces within which professionals must practise (Brint, 2001; Dent & Whitehead, 2002).

Furthermore, the term ‘professional’ itself is problematic, and its application in society today has been subject to numerous debates around who is called ‘professional’ and what it means to act ‘professionally’ (Evetts, 2011; Fournier, 1999; Freidson, 2001). In this thesis, however, I work with Fenwick and Nerland’s (2014, p. 2) definition of a professional as being a member of an occupational group “that defines itself as collectively sharing particular knowledges and practices, and that is publicly accountable for its service”. Scholars concerned with current engineering education and work emphasise the need for education practices to account for these changes in professionalism, and the need to develop ways to support students and practitioners to practise amidst these on-going tensions (Sheppard, et al., 2009; Shuman, Besterfield-Sacre, & McGourty, 2005).

Reconceptualising workplace learning perspectives

Finally, I argue that traditional understandings of workplace learning may be conceptually and practically insufficient to provide an accurate account of engineers' knowledge practices. The broad aim of workplace learning[1] research is to explore 'processes of development, movement and change in knowledge and practices that occur within particular activities and organizational arrangements of paid work' (Fenwick, 2008, p. 227). Gherardi (2017a) argues that the status of knowledge is an open-ended question; one that "can or should not be solved with a univocal definition; rather it is a definitional problem whose ambiguity may cause unintended misunderstandings" (p. bl). Thus, how knowledge is conceptualised, and what terminology and grammar is used to define it, has implications for how educators approach professional learning at work.

The dominant rational, cognitive, and human-centred perspectives in workplace learning position 'knowledge' as a reified, de-contextualised and de-materialised outcome (Guile, 2010). Metaphors of transfer encourage educational practices to simplify, codify and commodify knowledge (Hager & Hodkinson, 2009). This is also arguably the learning model upon which engineering education is traditionally based. For example, Sheppard et al., (2009, p. 12) argue that HE engineering students are commonly treated as rational problem-solvers, those who "learn as individuals, largely by applying formulas and rule to the solution of structured, 'right-answer' problems".

This cognitivist model has been criticised for ignoring the social and cultural dimensions of knowledge and learning processes. New metaphors, alternative vocabularies and different theories to conceptualise knowledge and learning were called for (Hager & Hodkinson, 2009). An important and influential perspective emerged in the 1990s, which positioned knowledge and learning as being socially and culturally situated and constructed, with an emphasis on participation (Hager, 2011). Lave and Wenger's (1991) situated learning theory

[1] While I use the term 'workplace learning' in this thesis, I acknowledge it is a problematic expression as it binds 'work' to a particular temporal and spatial locale, thus failing to reflect the changing nature of work as it spreads across time (working with colleagues and information on a global level) and space (the increasingly blurred boundary between home and work) (Fenwick, 2008; Mulcahy, 2011).

and their notion of ‘communities of practice’ (CoP) provided a crucial starting point for conceptualising knowledge and learning as being embedded in socio-cultural dynamics, which unfold in day to day activities, in the middle of work life.

A central tenet to CoP is ‘legitimate peripheral participation’, which stems from the observation that, when a newcomer comes to practise a particular practice, they do so primarily through interaction with others who are experienced; “who already know how it’s done” (Fox, 2006, p. 427). Knowledge and learning is thus increasingly understood as socially constructed – as “surrendering to a social habit” (Gherardi, 2001, p. 133) – and is contingent upon the participation and work practices of diverse individuals. While this participative theory has been expanded upon and modified by other scholars (Blackler, 1995; Brown & Duguid, 1991; Orr, 1996), it is not without its critics (e.g., Contu and Willmott, 2003; Fox, 2000; Handley, Sturdy, Fincham, & Clark, 2006), which I expand upon in the following chapter.

There has also been a growing recognition that the active role of materiality is often ignored or underestimated in analyses of professional work and education, and needs to be accounted for alongside the social (Fenwick & Edwards, 2010; Fenwick, Edwards, & Sawchuck, 2011; Orlikowski, 2007; Sørensen, 2009). Sociomaterial approaches have emerged to address this concern; those which consider the social and the material not as distinct entities but as interrelated enactments, or as being “constitutively entangled” (Orlikowski, 2007, p. 1437). Thus, “what we call the social is materially heterogeneous: talks, bodies, texts, machines, architectures, all of these and more are implicated in and perform the ‘social’” (Law, 1994, p. 2). I will now briefly expand on a sociomaterial understanding of knowledge and learning, as this approach is central to the unfolding of this thesis.

Sociomaterial approaches to knowledge and learning

Education and organisation scholars are increasingly working with various sociomaterial approaches to map the complex relations between professional work and knowledge, and to foreground the more nuanced, messy and materially-mediated aspects of practice (Fenwick & Edwards, 2010; Gherardi & Nicolini, 2000; Mulcahy, 2011; Roth, 1996). The sociomaterial theories that tend to be most influential in educational research and discussions include complexity science (e.g., Davis & Sumara, 2006), cultural-historical activity theory (CHAT) (e.g., Engeström, 1987) and actor-network theory (ANT) (e.g., Callon, 1986a; Latour, 1987).

These approaches share an educational aim to de-centre the traditional emphasis on the individual human subject, which positions 'knowledge' as a static and abstract idea that exists independently 'out there' to be acquired. Instead of placing the human at the centre of inquiry, metaphors of relationality, situatedness and emergence are favoured. These metaphors help to conceptualise knowledge and learning as being *performed*, or enacted, into reality, through relationships and connections. Scholars are deliberately choosing to use the active present continuous verb 'knowing' instead of 'knowledge' to reflect this performative perspective. This shift positions 'knowing' as having agency: it acts as "a driving force shaping the epistemic cultures and practices of the professions" (Jensen et al., 2012, p. 13).

From this point, I will consciously talk of 'knowing' instead of 'knowledge' to reflect this ontological shift, or drift (Thompson, 2011). Along these lines, I am drawn to Gherardi's (2001) concept of 'knowing-in-practice', to reconceptualise knowledge as *knowing* processes that are situated, distributed and material. Furthermore, to reflect my understanding that knowing processes are multiple performances, rather than singular constructs (Fenwick & Edwards, 2010), I extend this concept in this thesis and refer to 'knowing*s*-in-practice'. I will use this plural term when discussing specific engineers' knowings. However, when I refer to the concept of 'knowing-in-practice' more generally, I will retain the singular form.

To analyse how engineers' knowings-in-practices are enacted, and what effects they produce in their everyday work, I will be drawing on concepts from ANT that position knowing as a relational, embodied effect, emerging through dynamic social and material phenomena (Sørensen, 2009). ANT is considered a sociomaterial approach as it claims that both humans and non-humans are capable of exerting force.

Significance of the study

This study contributes to the growing field of sociomaterially-inspired research in education. To do so, this thesis marries current concepts and findings from workplace learning studies (e.g., Fenwick &, Nerland, 2014; Jensen et al., 2012), organisation studies (e.g., Nicolini et al., 2003; Orlikowski, 2007) and engineering work and education scholarship (e.g., Williams et al., 2014), to offer new ways of thinking about how education practices could better support students and practitioners to work in emerging industries. I contend that these are important areas to explore in more depth as it is through negotiating and balancing these tensions and challenges that particular knowings-in-practice emerge in engineers' everyday work; those that are often hidden by the dominant image of engineering education and work. Ultimately, I show how understanding what these knowings-in-practice look like from a sociomaterial perspective, and how various actors are implicated in their performance, can inform how educational practices are assembled to support future, and current, professionals for work in volatile, high-change emerging industries.

My original contribution to scholarship is the proposition of a phenomenon that I have termed a 'dynamic stability' sensibility. I contend that this phenomenon encapsulates some of the knowings-in-practice that are evoked in response to negotiating challenges and tensions that pervade professional work in an emerging industry. From a pedagogical perspective, I show that education practices that acknowledge a 'dynamic stability' sensibility can invite new questions about how to work in uncertain, opaque and unstable spaces, rather than striving for certainty and order.

Zukas and Malcolm (2002, p. 215) posit that pedagogy encompasses more than teaching and learning; that it "incorporates a critical understanding of the social, policy and institutional context". In this thesis, I use the term 'pedagogy' to denote a move beyond purely instructional methods to include critical educational approaches that consider how knowing and learning are produced, and the effects that they have on both students and education practices. Regarding the latter, I focus on how these critical approaches can inform education practices that are concerned with pre-service education and workplace settings. The broader professional issues that I map, and the phenomenon of 'dynamic stability', raise pedagogical questions about how education practices can better prepare and support students and professionals within the wind energy industry, and other emerging industries, where the flow of work is also volatile and unpredictable.

Overview of the study

This study is an ethnographic account of the everyday work practices of professionals – engineers – employed in a private-sector organisation in the wind energy industry. A specific group of professionals – engineers who all received an HE education qualification in an engineering discipline – and their practices were the focus of the ethnography. My aim was to attend to engineers' practices so that I could start to make visible knowing as a social and material dynamic emerging in their everyday work. The wind energy industry was considered as a case through which to explore these practices. I was hosted for six months by a welcoming and accommodating organisation in such an industry, which I have called TurboUK,[2] located in a Scottish city. From 1 October, 2012 to 16 March, 2013, I observed, followed, listened and talked with 13 engineers who had voluntarily agreed to participate in the study.

Three propositions underpin this investigation. Firstly, that a situated, on-going and distributed understanding of knowing may be more helpful than traditional cognitivist models to elicit ambiguous, complex and often taken-for-granted knowledge demands. This is important for this study because I want to move educational discussions beyond those of representation and "skills development" (Jensen, 2007, p. 491). To do so, I look to Gherardi's (2001, p. 132) concept of "knowing-in-practice", which appreciates that "the knowledge, the subjects and the objects of knowledge may be understood as being produced together within a situated practice".

I also see 'learning' as being embedded in the notion of knowing-in-practice. As Orlikowski (2002, p. 253) states, "when people change their practices, their knowing changes". I argue that this interdependent transformation can be

[2] TurboUK is a pseudonym.

understood as ‘learning’. Accordingly, questions of learning become implicated in questions of knowing. The focus of this study is not on prescriptive, linear and individualistic learning, but on the unanticipated and unpredictable refinement and emergence of local knowledgeable practices in order to enact ‘competent knowing’. I position ‘competent knowing’ as organisational action that is observably intelligible and rational, and produced through speaking, writing, and acting (Suchman, 2000; Gherardi, Nicolini, & Odella, 1998). I am calling this ‘refinement’ to perform competent knowing as an observable action ‘learning strategies’. These strategies are enacted through sociomaterial practices to allow for “an expansion of capacity for more sophisticated, more flexible and more creative action” (Fenwick, 2008, p. 228) in response to ever-changing circumstances. These notions of knowing-in-practice and learning strategies position knowing and learning as emerging in materially-mediated activities: they are inseparable from the doing.

The second proposition follows the first. If knowing is inextricably linked to doing, I look to Blackler’s (1995) recommendation that research on knowledge work should be centred on what people *do* in their work practice rather than what they know. This practice-based approach is increasingly being taken-up by scholars interested in mapping engineering practice (e.g., Jørgensen & Brodersen, 2016; Reich, Rooney, Gardener, Willey, Boud, & Fitzgerald, 2015; Chilvers & Bell, 2014). A practice-based perspective views the social world as being “brought into being through everyday activity” and it is these practices that are “understood to be the primary building blocks of social reality” (Feldman & Orlikowski, 2011, p. 1241). Although definitions of practice are often contested (Gherardi, 2009a), in this thesis I look to Schatzki’s (2001, p. 2) definition of practices as “embodied, materially mediated arrays of human activity centrally organized around shared practical understanding”. A crucial element of this definition is the notion of practices as being ‘materially mediated’.

This guides me to the third proposition: to study professionals’ practices without considering both social and material entities, and their co-constitution, would, I argue, provide a limited account of how professionals enact knowing and learning at work. Therefore, I draw on sociomaterial approaches to foreground the materiality in researching knowing-in-practice. In her study of the materiality of learning, Sørensen (2009, p. 177) defines ‘materiality’ as the “the achieved ability to connect with other entities”. Leonardi (2012) argues that, until recently, whilst most sociomaterial studies have served to show that the social and the material are connected, they fall short of showing *how* the entanglement occurs. To address how different human and non-human entities come together in gatherings, or assemblages, to perform knowledge practices as effects, I look to theoretical concepts that have emerged from Actor-Network Theory scholarship. I explain this theoretical perspective more fully later in this chapter.

These three propositions – knowing-in-practice, materially-mediated practice as the unit of inquiry, and sociomaterial understandings of knowing and learning – form the basis of my research approach to this study, and they guide how I address the following research questions.

Research Questions

1. What tensions are professional engineers negotiating as they work in a volatile, high-change, emerging industry?
2. What knowings-in-practices and learning strategies are evoked by these tensions?
3. What are the pedagogical implications of a practice-based, sociomaterial understanding of engineers’ everyday practice for pre-service education and workplace settings?

I looked to ethnography as a methodology to allow me sufficient space, time and access to a research setting so that I could trace social and material relational accounts in detail and *in situ*. I attended the TurboUK office for two-to-four days a week, totalling over three hundred hours. Each day I was invited to attend meetings with the engineers or observe them as they worked at their desks, in meeting rooms, or on a wind farm site. At the end of the day I completed a daily report to structure my written observations. I also scheduled three semi-structured interviews with each of the 13 participants, which I audio-recorded and transcribed.

As I was adopting a relational, sociomaterial perspective, I wanted to foreground the role of the many materials that were integral to engineers' practices. A crucial issue of studying knowing and learning at work is that many of the workplace routines are tacit or taken-for-granted, and thus hard to explicate, especially during a single interview (Eraut, 2000). Therefore, I needed to find new or different methods that would offer a more powerful insight into engineers' materially-mediated practices than traditional interviews. I developed three visual and creative exercises to encourage participants to reflect on how the active role of material artefacts helped, or indeed hindered, their everyday work: a relational map exercise, the "Interview to the Double" (Nicolini, 2009), and a photo-elicitation interview (Collier Jr., 1957). I combined each exercise with one of the three semi-structured interviews. I explore these methods in further detail in Chapter 3.

Before I present an overview of the theoretical resources, I turn back to look more closely at the case I chose to situate this study, and further untangle some of the key tensions and challenges facing engineers working in this industry.

Introducing the case: Wind energy as an emerging industry

In this section, I explain what constitutes an 'emerging industry', and clarify how I work with the term 'emerging'. I then provide a background about the renewable energy sector and wind energy industry, depicting some of the key actors that gather together to stabilise professional knowledge in a growing industry.

What is an 'emerging' industry?

A PricewaterhouseCoopers report (Monfardini, Probst, Szenci, Cambier, & Frideres, 2012) set out to define the characteristics for 'emerging industries'. They argue that there is no "single, commonly accepted and operational definition of 'emerging industries'" (p. 7) due to the varying spheres from which research into emerging industries has been conducted. Therefore, using this report as a guide, I will be defining an 'emerging industry' as an industry that has:

- entered into being as response to new socioeconomic conditions and challenges (such as climate change);
- been created as part of a completely new, or restructured, industrial sector;
- high growth potential (it tends to grow at a rate faster than the overall economy), but also acknowledges the risk of decline and failure;
- a high degree of uncertainty because the industry itself, the product demand and the supply base are still unpredictable;
- a large network of cross-sector support, characterised by knowledge spillovers often between professional and geographical boundaries; and
- a capacity that nurtures entrepreneurship and encourages innovation, both of technologies and of organising.

(Adapted from Monfardini et al., 2012)

One emerging industry that is being positioned as increasingly integral to today's socioeconomic, educational and political challenges is that of wind energy, in the renewable energy sector. Here, a 'sector' can be defined as "a set of activities which are unified by some related product groups for a given or emerging demand and which share some basic knowledge" (Malerba, 2005, p. 65). Within a sector, industries (comprised of groups of organisations and firms) are related through their commonalities but, at the same time, will remain heterogeneous.

Clarifying the term 'emerging'

I gathered the literature and data for this study over five years ago. At that time, it was reasonable to claim that the wind energy industry was still emerging, but, in the last two years, due to changing social, economic and political factors, the industry is experiencing periods of decline. So, although the wind energy industry may no longer be termed 'emerging' in a nascent sense, I argue that it is still emergent in its volatility. Furthermore, the term 'emergent' reflected the organisation (TurboUK), which was growing at the time of the study (and continues to do so at the time of publishing), as well as reflecting the general state of the wind energy industry and renewable energy sector in 2013/14.

Renewable energy sector and the wind industry

The UK and, in particular, the Scottish Government, has been prioritising the growth of emerging industries to tackle recent political and economic difficulties (Department of Energy and Climate Change, 2013; Scottish Government, 2011). Scotland has long been a resource-based energy economy and, in the *2020 Routemap for Renewable Energy in Scotland* (2011), the Scottish Government set out its aim to produce the equivalent of all of Scotland's electricity from renewables by 2020. Renewable energy can be defined as "energy derived from natural processes (e.g. sunlight and wind) that are replenished at a faster rate than they are consumed" (International Energy Agency, 2017, n.p.). Work related to wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases can be included in the renewable energy sector.

In this thesis, I will work with the wind industry as a case of this sector. While wind has been harnessed for electricity for centuries, the first commercial wind farm in the UK was built in 1991 in Delabole, Cornwall (Johnson & Jacobsson, 2001). Wind energy has now established itself as the forerunner of renewable energy generation and, as the cost of producing such energy decreases and the pressure to address CO_2 emissions increases, the trend is likely to continue. There are an estimated 7,837 turbines now operating in the UK on and offshore in a bid to reach the current UK government's target of generating 15% of all the UK's energy from renewables by 2020 (HM Government, 2009). With jobs expected to grow substantially, and with technology continuing to be innovated, this sector can be classified as emerging (as clarified in the previous section).

Industries within the renewable energy sector attract a wide range of engineers: civil, electrical, mechanical and aeronautical. Some renewable energy organisations emerge from within a large, already established energy company. For example, a fossil fuel industry will develop a sub-group to tackle renewable energies. Other industries have emerged *de novo* and therefore are faced not only with creating a profitable product or service in the sector, but also with developing and stabilising their work activities and organising processes. The latter best describes TurboUK.

Legitimising and stabilising an emerging sector

I do not consider the wind energy organisation to be a bounded, closed entity: people, documents, tools, and theories from other places continuously pass through (Vinck, 2003). It is intrinsically entangled with wider networks of actors that contribute to legitimating and sustaining the sector (Aldrich & Fiol, 1994). The 'legitimating process' that encourages a move towards a professionally recognised sector is spread out among actors such as "cooperative alliances, trade associations, scientific societies, and other network bodies" (Choi, Park, & Lee, 2011, p. 774). The coordinated activity by these bodies "creates critical mass, stimulates actors in setting high expectations and accelerates the general public's acceptance of the emerging technologies". Thus, the stabilisation of a sector could be viewed as a highly tentative, social and distributed practice.

Furthermore, the actors involved in the legitimating process generate and champion different knowledge domains, which jostle together to help shape education practices (Gherardi, 2015). For example, existing professional institutions, such as the Institution of Mechanical Engineers,[3] influence HE curricula in energy-based courses, as well as validating training courses by external providers. The relatively recent creation of renewable energy non-for-profit trade associations and registered charities[4] contribute their knowledge practices to professional work, shaped by political and ethical agendas. In the UK Government, a specific policy department, the Department for Business, Energy and Industrial Strategy (DBEIS), was established in 2016, which "brings together responsibilities for business, industrial strategy, science, innovation, energy, and climate change" (DBEIS, 2016, n.p.), and imposes a regulatory power that legitimises and standardises professional knowledge. This brief depiction of the various actors involved in shaping the demands for engineering knowledge

[3] www.imeche.org
[4] These include, for example, RenewableUK (www.renewableUK.com) and Renewable Energy Association (www.r-e-a.net), and Renewable Energy Foundation (www.ref.org.uk)

begins to highlight how professional knowledge emerges as a socially situated practice, rather than as a decontextualised, stable entity.

In this study, while I recognise this interrelatedness of different knowledge domains that shape engineers' education practices, I am interested in speaking to the education practices that inform HE institutions and workplace settings, rather than non-for-profit organisations and policy. As I mentioned in the opening paragraphs of this chapter, I view work and education practices as being mutually dependent in shaping professional work and knowing. As current education practices are struggling to account for complex, ambiguous and unpredictable demands in emerging industries, I contend that it is important to map in more detail the current challenges and tensions that are facing engineers in their everyday work. This is the purpose of the next section, which draws on workplace learning, organisation, and engineering studies scholarship to further highlight the significance of the research questions that guide this study.

Key challenges and tensions in engineering work and education

The following section explores six tensions and challenges that persist in engineering work and education.

Engineering as a technical and/or social activity

One tension facing engineering practice emerges from the received ontological position that treats the social and the technical as separate entities. Education practices tend to treat engineering work as an inherently technical endeavour, which fails to account for the social aspects of engineering activities (Bryce, Johnston, & Yasukawa, 2004). In this techno-centric perspective (Orlikowski, 2010), 'technology' is often treated as a 'false solidity' (Bloomfield & Vurdubakis, 1994) in that it is uncritically viewed as a given entity available to study in isolation from the particular relations in which it operates. Its outcomes are understood to be stable and inevitable for those who engage with it (Feldman & Orlikowski, 2011). As such, education practices are often based on a disengaged, technical and linear model of business and project management, with a nod to the social competencies at the periphery (Solomon & Holt, 1993).

However, there is now considerable recognition in scholarship that the divide between the technical and social is unnecessary, and, in fact, misleading (Orliksowki, 2007; Suchman, 2000). Suchman (2000) worked with Law's (1987) notion of 'heterogeneous engineering' to explore how the work of bridge-building involves the precarious alignment of human and non-human entities into a stable artefact. She showed that the 'technical' aspects of engineering work are embedded in extended networks of organisational 'social' activities, including "sense-making, persuasion and accountability" (p. 315). Interviewing 55 engineers, Trevelyan (2007) found that a social dimension of work, which he termed 'technical coordination', was a prominent aspect of engineers' practice. He defines technical coordination as "working with and influencing other people so they conscientiously perform some necessary work in accordance with a mutually agreed schedule" (p. 191), often in the absence of formal authority. In their study of Portuguese engineering experiences, Williams and Figueiredo's (2014) findings support Trevelyan's (2007) work. They argue that novice engineers spend extensive periods of time overseeing people on site, attending meetings, and making telephone calls. These studies, among others, are showing that engineering work *is* organising work. As Law (2011a, p. 7) argues, we cannot "think of the social as some kind of an addition that can be 'bolted on' after the engineering has been done".

In response to this viewpoint, some scholars have argued that engineering work should be reframed as a "human social performance" (Trevelyan, 2010, p. 187), which brings the social in to the core of engineering education. Consequently, many education practices frame these non-technical competencies as "generic graduate attributes" (Barrie, 2007, p. 439) or "professional skills" (Shuman et al., 2005, p. 41) which are taught to undergraduates alongside their engineering degree. The assumption is that these skills can be framed as 'best practice' and that they will be transferred unproblematically into different work situations (Hager & Hodkinson, 2009). However, whilst this reframing counters the techno-centirc perspective, these education practices reinforce the divide between the social and the technical (Johri, 2011), and position knowledge as something to be acquired.

In this thesis, I propose that adopting a sociomaterial perspective can help to position engineering practice as a co-constitutive social *and* technical achievement. Mulcahy (2012) calls this approach “a matter of seeing double”, where one is “impelled to give attention, at one and the same time, to its *socialities* and *materialities* … Seeing double is a matter of taking associations or connections or relations into account” (p. 125, original emphasis). To help me ‘see double’, I will look to Law’s (1987) concept of ‘heterogeneous engineering’ to explore how a network of different materials – people, technologies, texts – are assembled into a product or effect. I explore this notion of ‘heterogeneous engineering’ in the next chapter, and, in Chapter 6, I work with, and extend, this concept through my empirical account of engineers’ practices.

Unstable and uncertain knowledge base

The next tension emerges from a wider concern that professional work is now characterised by an increase in the circulation of uncertain and unstable knowledge. As Fenwick et al. (2012a) point out, professionals’ work has been traditionally underpinned by “the capacity to perform work in ways that are informed, guided by, and validated against shared knowledge and established conventions for practice” (p. 3). However, due to the emergence of the information society and the proliferation of knowledge resources, the notion of ‘expert’ knowledge is becoming blurred and contested, which generates risk and insecurity in professional work (Jensen et al., 2012). Professionals are thus invited to undertake new and different responsibilities for knowledge (Fenwick et al., 2012a).

A responsibility for professionals working in an emerging industry is establishing a new, or different, collective knowledge base amidst wider issues of uncertainty and instability in the status of professional knowledge. In their study of a new field, digital humanities, Kaplan and Vinck (2014) found that engineers practising in this field were often confronted with completely new situations, where methods, paradigms, processes and standards were not yet established and validated. In such instances, they showed that engineers were having to piece together knowledge practices from existing methods, as well as having to generate new strategies. Thus, knowledge is often practice-generated.

Furthermore, in an ethnographic study of six US engineering firms, Anderson, Courter, McGlamery, Nathans-Kelly, and Nicoment (2010) revealed that engineers' practices were performed as distributed and fragmented activities, which involved high levels of uncertainty. They claimed that problem-solving was "not logical or effectively coordinated; instead it lacks clear structure and is perpetually unpredictable, repetitious, inefficient, and uneconomical" (p. 154). Therefore, knowledge was being performed continuously in the moment. These practice-based, uncertain, and continuously performed understandings of knowledge processes are at odds with traditional education practices that present engineering knowledge as rational, stable and logical (Sheppard et al., 2009).

Therefore, to be able to inform future education practices, I contend that further exploration is needed to map how engineers are navigating and negotiating problem-solving in these uncertain, unstable and ambiguous spaces. Perhaps these spaces are crucial to be able to enact competent knowing in emerging industries, as they afford discretionary decision-making and flexibility to discover new knowledges, strategies and ways of organising. For example, there is often inadequate information available to the engineer to complete the work required (Trevelyan, 2010). Sheppard et al. (2009) point out that, in these situations, engineers must decide when to move a project forward to satisfy the employer's and client's wishes, and when to stall the work to allow for more complete information to be gathered, and ensure health and safety is adhered to in their professional role. This links to the next tension that engineers are facing, where engineers' practices are being heavily influenced by demands from external forces and, as such, they must attend to multiple stakeholders.

Attending to multiple stakeholders in widening networks

While traditional engineering education tends to position engineering activities as being separated from 'external' forces (Trevelyan, 2014), practice-based studies of engineering work have shown that they are heavily influenced and shaped by numerous heterogeneous actors, such as government bodies, local community groups, clients, banks, and even the media (Suchman, 2000; Trevelyan, 2014). This requires professionals to engage with epistemic cultures and practices outside of their traditional sector. However, this engagement is often characterised by multiple over-lapping agendas and perspectives, which need to be negotiated and balanced. For example, the product of the engineers' practice in this study – a successfully operating wind turbine – is not an apolitical technical achievement, but is at once a political statement by energy ministers, a source of job opportunities, an aesthetic art form, a community appeal, an enactment of environmental policy, and a landowner's goldmine. Furthermore, these competing perspectives and agendas are not progressively introduced along the way, but are inextricably present, and enacted, from the first moment an engineering process is bought into question (Callon, 1987).

One stakeholder who has increasing prominence over the shaping of engineers' practices is the customer, or client. Dinovitzer, Gunz and Gunz (2015, p. 126) refer to the "power of the client", which threatens the autonomy of the professional, and raises ethical questions. Leicht and Fennel (2001) introduce the term "client capture" to characterise this tension, where the demands of the client can put pressure on how the professionals' time, resources and costs are allocated, and "the consumer becomes sovereign" (p. 106). This positions professionals as having to balance between what has been termed "the logic of the market" and the "logic of professionalism" (Evetts, 2012, p. 3). Evetts (2012, p. 5) describes this shift in professionalism as, "one foot in the market and the other in collegial solidarity and ethically-based occupational controls". For engineers, they must balance the tension between the need to market and sell an engineering product or service, and please the client and employer, whilst still abiding by their professional warranty as a qualified engineer.

Therefore, to be able to operate within "circuits of knowledge that exceeds the boundaries of local work practices" (Jensen et al., 2012. p. 4), and respond to various stakeholder demands, engineers have to perform numerous roles that are social as well as technical (Faulkner, 2007). These can involve complex negotiation and sales strategies, relationship-building, ensuring credibility, responding to market dynamics, and ethical and discretionary decision-making. Thus, engineering practices are not just concerned with technical activities, but are performed in multiple layers, drawing on different networks and circuits of knowledge.

Education practices, which are dominated by knowledge practices based in mathematics and physical sciences, may be better served by an appreciation of other disciplines, or connections with other disciplines, that can address some of these social and technical demands. For example, Sheppard et al. (2009) point out that some engineering enterprises necessitate knowledge from marketing, finance and sociology domains. In this thesis, I will pay close attention to the widening networks that are implicated in engineers' practices, and what knowings-in-practice emerge as engineers respond to the complex demands created by multiple stakeholders. This leads on to the next challenge emerging for professionals in response to these complex demands and need for different circuits of knowledge: new organising dynamics that support collaborative practice.

Collaborative working in distributed practices

Tyre and von Hippel (1997) point out that collaborative processes are becoming increasingly vital in industry to coordinate heterogeneous activities because no one person or team embodies the necessary knowledge to tackle the progressively complex organisational problems and tasks. In engineering, different professionals (both within engineering fields, and from other occupational groups) are increasingly coming together to benefit from each other's distinct professional expertise (Anderson et al., 2010; Bucciarelli, 1994; Trevelyan, 2010; Vinck, 2003). For example, Schmiede and Will-Zocholl (2011) studied engineering work in the German automotive industry, and highlighted the need for interdisciplinary cooperation between electrical, mechanical and software engineering to respond to the complexity of the work activity.

The notion of 'projectification' (Ekstedt, 2009; Midler, 1995) – the creation of small temporary teams within an industry to focus on project-based activities – is increasingly used in engineering organisations to address the day-to-day implementation of work to deliver a service (Gainsburg, Rodriguez-Lluesma, & Bailey, 2010). Because of an increase in interdependent ways of working and 'projectification', the role of engineers in the workplace is shifting: "whether formally or informally, an increasing number of engineers are playing the role of boundary spanners and are brokering knowledge across geographic boundaries"

(Johri, 2008, p. 1). Not only are these engineers bridging disciplines (Adams & Forin, 2014) and spanning different knowledges over boundaries, Anderson et al. (2010) found that these different ways of working required professionals to enact new knowledge strategies, as well as negotiate conflicts that may arise between the epistemic cultures, ideologies and motivations of different groups. These situated, distributed and often contested performances of different knowledge domains are traditionally not reflected in current education practices, which tend to treat disciplines as stable, bounded and singular constructs.

In this thesis, I am interested in investigating how infrastructure is constitutively entangled in the different ways work is ordered and organised, particularly from a relational perspective (Star & Ruhleder, 1996). I explore the literature on relational infrastructure in more detail in Chapter 5, where I introduce the term *infrastructuring* to show how “technologies, people and processes come together and make up the working relations that are necessary to perform work” (Mathisen & Nerland, 2012, p. 71) and explore how ‘projectification’ can be considered as an infrastructure practice.

Negotiating boundaries of acceptable practice

Balancing multiple demands from employers, clients, policies, and contractors can often position engineers in spaces where following codified or formalised procedures will not achieve the desired outcome. Instead, implicit practices that work together to support and frame the more explicit practices are mobilised. In her bridge-building study, Suchman (2000, p. 313) writes about how an organisation member learns to become competent through demonstrating “artful compliance”. That is, the ability to learn how to work through intelligent and rational organisational actions is balanced against an adherence to technological and professional disciplines and values. To achieve this artful compliance, she makes the point that it will “necessarily involve endless small form of practical ‘subversion’, taken up in the name of getting the work of the organisation done” (p. 313). However, a key tension here is figuring out what constitutes ‘acceptable’ in the enactment of these more ambiguous, informal ‘subversive’ practices, and when this steps over into unacceptable practice.

Williams and Figueiredo (2014) provide evidence of this tension in their findings. One of their participants, a civil engineer, encountered an ethical dilemma when discussing delivery dates with her client. She remarked that it was a well-known response in the engineering market to lie about delivery dates and promise shorter timescales than they intended. If she did not do this, and remained completely honest about the timescale, then the client would give the project to a competitor who would take the same amount of time, but would have lied to secure the contract. It could be argued that lying to secure the contract in this situation was enacted as discretionary decision-making. Evetts (2002, p. 345) defines discretion as “having the power and control to exercise one’s own professional judgment in carrying out and making decisions in the daily work”, and argues that discretion is a crucial characteristic of professionalism today.

In this thesis, I will focus on how newcomer engineers are grappling with discretionary decision-making as a more-than-human performance. I show how sociomaterial processes unfold to define the boundaries of these acceptable practices, and what these may look like in an emerging industry where practices are still being established as ‘accepted’. I argue that it is necessary to explore the knowings-in-practice and learning strategies involved in calibrating what constitutes ‘acceptable’ practice to inform how educational practices can respond to such local, complex, and nuanced issues, such as lying about delivery dates to ensure a contract is secured, that might arise in everyday work. However, it is important to note that on the other end of the ‘acceptable’ practice spectrum is ‘bad’ practice. This type of practice has serious legal and ethical implications, such as the highly-publicised malpractice in the Enron scandal[5] and the Harold Shipman[6] case. I now turn to the final tension, balancing innovation with continuity.

[5] Enron was the world’s largest energy trading company which filed for bankruptcy in 2001. It was revealed that Enron had lied about its profits and concealed debts that resulted in investors losing billions of dollars. Consequently, the Sarbanes-Oxley Act (2002) was introduced, which increased accountability and transparency in corporate management http://logitax.hu/SOX.pdf [accessed 08/01/17].

[6] Harold Shipman was an English medical doctor who was convicted of killing over 200 of his patients between 1974 and 1998. This had serious ramifications for the core professional value of doctor-patient trust. The case revealed the fragility of the current health care regulatory system and prompted medical profession to review regulation procedures (Smith, 2002).

Balancing innovation with continuity in work

Another tension that I highlight relates to innovation practices. Innovation is often cited as a key capacity for engineers to enact in today's industries to remain competitive (David & Foray, 2002; Radcliffe, 2005). However, in this thesis, I am not referring to innovation in the managerial or entrepreneurial sense. Star (1991) argues that this view of innovation champions an individual with the creation or discovery of new a process or a product, and is concerned with innovation as a source of profit. Instead, I position innovation as an on-going, everyday activity, through local and implicit work practices (Gherardi, 2000; Sørensen, 2009). For example, in their studies of large US corporations, Suchman and Bishop (2000, p. 332) point out that innovation is a constant aspect of everyday work practice: "even to keep things going on 'in the same way' in practice requires continuous, mundane forms of active appropriation and adaptation of available resources – discursive and material – to the circumstances at hand". This modest understanding of innovation is often taken-for-granted by practitioners, and rarely made visible in scholarship (Suchman & Bishop, 2000).

This is an important understanding of innovation to help foreground a particular tension in everyday work: the on-going balancing act between innovating and stabilising processes. To respond to rapid changes, multiple knowledge sources and different perspectives, engineers' practices must remain flexible and fluid. Furthermore, for organisations related to emerging industries, technologies and organising processes may still be developing, and improvisation and creativity are valued as crucial growth activities. Yet, on the other hand, Weick and Westley (1996) contend that the need to innovate and learn is held in tension with the drive to organise: to order and stabilise. As Fenwick et al. (2012a, p. 3) point out, this stabilisation of knowledge and practices is necessary to maintain continuity in professional work.

In this thesis, I will look to Ellström's (2010) concept of practice-based innovation to explore this tension with relation to knowing and learning. Ellström (2010, p. 37) proposes that practice-based innovation occurs in balancing "the logic of production with an emphasis on the mastering and reproduction of prescribed work processes" with the "logic of development with a main focus on exploration and re-conceptualisation (reconstruction) of the operations that are performed in practice”. He argues that it is from amidst the tensions and contradictions between the two logics that potential opportunities for learning emerge. Thus, my understanding of innovation in this thesis is inextricably bound-up with issues of knowing, working, and learning (Brown & Duguid, 1991; Gherardi, 2011; Orr, 1996). Understanding in more detail what knowings-in-practice and learning strategies emerge in this tension can inform education practices how to approach innovation from a more local, modest and situated perspective.

In summary, I have shown through mapping out these six tensions and challenges that there is a pressing need “to understand professional practice beyond individual decision-making, beyond stable communities and beyond given knowledge” (Fenwick et al., 2012a, p. 3). In the next section, I provide a theoretical overview which delineates how I could explore professional practice as a collective, unstable and uncertain performance.

Theoretical overview

As practice is often messy and slippery, attempts at grasping, or ‘catching’ practice, without reifying it, is a challenge for the researcher (Nicolini, 2009; Reich, Boud, Gardner, Rooney, Willey, & Fitzgerald, 2013). In this section I provide a brief overview of the sociomaterial theoretical approach, Actor-Network Theory (ANT), that I adopted in this study to address this challenge. Working with ANT concepts has enabled me to ‘catch’ practice momentarily by translating a collection of engineering practices into an empirically grounded case.

The aim of an ANT empirical investigation is for the researcher ‘to follow the actor’ (Latour, 2005, p. 12): to trace the tiny details of a practice wherever they may lead. This includes following material as well as human traces along an “empirically traceable path … where the ingredients entering into the interactions appear to come from” (p. 139). Specifically, it is the relations, or the “*type of connection* between things” (Latour, 2005, p. 5, original emphasis), which an ANT approach is concerned with tracing. At these points of connection, human and non-human actors translate, or change, each other to become part of an assemblage of coordinated materials and action; a particular and local knowledge, object or practice. The gathering of actors that have been heterogeneously assembled through the efforts of alignment and the associated translations is considered a 'network'. Thus, education scholars who work with ANT tend to conceptualise 'knowledge' as a relational, networked effect generated through the alignment of heterogeneous actors (Fenwick & Edwards, 2010).

The appreciation that both human and non-human actors are treated as symmetrical is a central premise of ANT (Callon, 1986a; Latour, 1987). However, Latour's work has been criticised for flattening out subjects, of engaging in 'symmetrical absurdity' (McLean & Hassard, 2004). Indeed, in this thesis, I struggle to reconcile with Callon (1986a) and Latour's (1992) notion of radical symmetry because I am interested in exploring how professionals – humans – know and learn, not objects. Thus, I do not want to radically de-centre the human in my argument. It is the co-constitutive relations between humans and non-humans, and what effects emerge from these connections, that are of interest to me in this study. After all, as Edwards (2010, p. 6) points out, the 'post' in post-human is not anti-humanistic: "it is not 'after' in terms of going beyond, but in terms of offering a constant experimentation with or questioning of the human". Therefore, I am interested in an ANT perspective because it considers knowing as more-than-human performances.

While 'translation' and 'networks' (Latour, 1987) are key concepts that I work with in this thesis, I go beyond Latour's ANT writings to bring in other scholars, such as Bowker and Star (1999), Suchman (2000) and Orlikowski (2002). In particular, I am drawn to the later work of Law (2007) and Mol (2002), which focuses on the performativity of objects and the realisation that there could be multiple enactments of an object, not just different perspectives. Notions of fluidity, performativity, multiplicity and in/stability emerge as pivotal concepts, which I work with, and expand on, to guide my analysis. I also explore how different scholars are looking more closely at the mediating role of objects to highlight engineers' knowledge practices at work.

How ‘objects’ matter in researching engineers’ knowing

As many engineering scholars have pointed out, engineers use ‘things’ every day (Bucciarelli, 1994; Henderson, 1999). Their worlds are filled with stuff: drawings, sketches, bits of electrical equipment, mobile phones, and so on. Sometimes, these objects are so taken-for-granted, or mundane, that they do not even register that they are part of their everyday practice. Yet, increasingly, education and organisation studies have shown how theorising the role of objects and material artefacts in workplace activity can be useful to analyse knowledge practices, such as cross-collaboration (Nicolini, Mengis, & Swan, 2012), coordination (Carlile, 2002), partnering (Bresnen, 2010; Windeck, Weber & Strauss, 2015) and cooperation (Boujut & Blanco, 2003). Depending on the way the object is being used in practice, different theoretical approaches have been proposed to explore its effects, such as affiliative object (Suchman, 2005), epistemic object (Knorr-Cetina, 1997), and boundary objects (Star & Griesemer, 1989). In this thesis, I look both to the notion of boundary objects, and to what Law and Singleton (2005) call ‘fluid’ objects, to understand how the relationality of objects evoke certain knowings-in-practice.

What is perceived to be an ‘object’ in this study warrants an explanation. Throughout this thesis, I present different accounts of activities from the perspective of the participants: engineers who often treat the objects of their practice as stable, unitary entities. However, I am attending to these objects from a sociomaterial perspective. This perspective considers that objects, like technologies, are things whose operation and outcome are not fixed or prescribed, but are emergent through precarious interactions with humans and other non-human entities (Feldman & Orlikowski, 2011). Thus, I am attuning to the complexity of the human and material relations that perform an object, and acknowledge that they are precarious achievements rather than stable entities.

In the next chapter, I explore the theoretical underpinnings of knowing-in-practice and ANT in more detail, alongside the sensitising concepts that I have chosen to explore knowing as a relational, materially-mediated performance. Before I travel further into this thesis, however, it is worth mentioning that I am not a practising engineer, nor have I ever studied engineering. My interest in the changing practices of professionals working in emerging industries has sprung from pedagogical questions that have arisen during my professional, and personal, life. I now take a step back to explain how I have arrived at the questions, theories and musings that I have posed so far.

Asking questions: The unfolding of a professional inquiry

My professional interest in issues of knowing and learning, and exploring the nexus between HE and work settings, began during my undergraduate studies in the field of psychology. My professional journey echoes that of educational scholar, Sørensen (2009), who also studied psychology at university. Vygotsky's (1978) Social Development theory and Lave and Wenger's Situated Learning theory (1991) played an important role in my early understandings of knowing and learning. As my experiences in studying and working in professional education grew, I began to find their work limiting in accounting for the increasing complexity and uncertainty that pervades our working and learning lives. I briefly turned to management and HRD-based education opportunities to look for alternative understandings of learning and work. However, I found that these reproduced some of the more cognitive and rational perspectives of knowing and learning that I found unhelpful, such as 'knowledge transfer'.

It was not until I accepted an opportunity to study a Master's in Educational Research within the Professional Practice, Education and Learning (ProPEL) research network at the University of Stirling that I was introduced to sociomaterial approaches. In parallel with Sørensen's journey, discovering these approaches has afforded me an empirical approach to analysing the materiality of knowing and learning. Accounting for materiality has helped me ask, and explore more deeply, some of the more complex questions about education and workplace learning.

Running parallel to these transitions in my professional journey were significant changes in my personal journey. In the height of the recession in 2009, I relocated to Scotland from London for my husband's job. He was a project manager, managing the installation of wind turbines for a renewable energy company. In the drought of the recession, this was one industry that was blooming. I was soon employed at a local university and, when explaining to my colleagues that I had spent my weekend up a mountain, eating a packed lunch in a 4X4 pick-up truck, and watching the painstakingly slow installation of 80-metre high turbines (see Figure 1), I was often asked whether they could talk to my husband's employers. They were desperate to know, "How do we design a course for students entering professions in the renewable energy sector?" Their interest led me to two important conclusions. Firstly, wind energy seemed to be high on the social, political, public and economic agenda in Scotland for multiple parties, and this had a direct effect on education planning and provision. Secondly, educators were uncertain what form the HE curriculum should take to respond to the needs of this emerging industry.

Figure 1: My weekends spent up a mountain on a wind farm site

Around this time, a PhD opportunity presented itself at University of Stirling, again within ProPEL. I decided to merge my two journeys to critically explore how knowing and learning could be reconceptualised through a sociomaterial approach, to prepare students, and support practitioners already in work, for work in emerging industries.

What follows in this thesis is an account of the assemblage through which my hybrid journey travelled, presenting both the mapping and the reflection of the theoretical landscape, the methodological strategy and their consequences, the insights that were gained along the way, and the conclusions that I have drawn in arriving at the other side.

Chapter 2: Mapping a theoretical landscape from a sociomaterial perspective: Knowing-in-practice and Actor-Network Theory

In this thesis, I am not looking to 'solve' the problem about how professional knowing and learning should be forevermore conceptualised, but to "expose some of the contingencies and uncertainties – ethnographic, theoretical, personal and political – with which I have wrestled along the way" (Law, 1994, p.17). To make visible these different possibilities, I draw on theoretical concepts that disrupt dominant understandings of knowing, and invite me to conceptualise knowing as a relational, situated and material performance. In this chapter, I explore the landscape of two sociomaterial, practice-based theoretical approaches: knowing-in-practice and Actor-Network Theory (ANT).

This chapter unfolds as follows. Firstly, I explore the concept of practice and explain how the notion of knowing-in-practice relates to practice scholarship. I emphasise three aspects of knowing-in-practice that are central to my study: embodied and aesthetic engagement; collective know-how; and on-going, materially-mediated action. I then turn to build on the introduction of ANT that I presented in Chapter 1, focusing on how I work with Latour's (2005) directive 'to follow the actors'. I discuss how I am drawing on the ANT concept of translation before deliberating the gathering metaphors, 'network' and 'assemblage'. I then move to consider other helpful ANT concepts of ordering, performativity and multiplicity. Law's (1987) notion of 'heterogeneous engineering' is explored in relation to engineering practice, and I discuss how notions of fluidity and in/stability are implicated in this concept. Finally, I address issues of power relations, and explore how I can work with theoretical concepts to trace the mediating role of objects in engineers' everyday knowledge practices.

Practice

As I mentioned in Chapter 1, an important move in workplace learning is one that illuminated the potential of viewing knowing and learning as a sociocultural dynamic (Hager, Lee, & Reich, 2012). In particular, Lave and Wenger's (1991) notion of 'community of practice' foregrounds the importance of considering *practice* as being integral to issues of knowing and learning at work. This development coincided with what some have been calling a 'turn to practice' (Schatzki, 2001), or a 're-turn to practice' (Miettinen, Samra-Fredericks, & Yanow, 2009), in social science. Practice, in general terms, refers to emergent activities in everyday life that are embedded in routines, norms, and collective beliefs and values, and are performed, and re-performed, through material, symbolic and emotional resources (Bourdieu, 1990). The concept of 'practice' is one of the three propositions that underpin this study and needs further untangling in this chapter.

Corradi, Gherardi, and Verzelloni (2010) note that a proliferation of practice-based studies has created a 'bandwagon', which has led to the institutionalisation and accumulation of a community of scholars who work with the concept of practice in a variety of ways. While being closely associated with organisation literature, the concept of practice has prominence for education research, as it focuses on how knowing and learning emerge in work, which is a central issue in workplace learning research. Reviewing the practice-based literature has helped further my understanding of knowing and learning as a situated, on-going accomplishment that is shaped by material, historical processes, rather than a process of applying cognitive structures to specific situations. I am particularly interested in how a focus on practice can highlight the intangible and complex aspects of knowing and learning in everyday work (Gherardi & Nicolini, 2000; Orlikowski, 2002; Schatzki, 2001). In the following passages, I discuss how I am working with the concept of practice to help conceptualise engineers' knowing in their everyday work, and I identify where my study sits on the bandwagon of practice-based studies.

Knowing-in-practice

Corradi et al. (2010) highlight that, while the bandwagon of practice-based studies has been trundling steadily forward, there does not exist a widely accepted definition of what practice *is*. Feldman and Orlikowski (2011) point to three interrelated features that are common to those choosing to work with the conceptualisation of practice:

1) that situated actions are consequential in the production of social life;
2) that dualisms are rejected as a way of theorizing;
3) that relationships of mutual constitution are important (p.1241)

The polymorphous nature of the term ‘practice’ is explored in several helpful articles (e.g., Corradi et al., 2010; Feldman & Orlikowski, 2011), which highlight subtle but important differences between, among others, ‘practice-based perspectives’, ‘practice lens’, ‘practice theory’, and ‘knowing-in-practice’. It is the latter approach to practice, knowing-in-practice, that I work with in this study.

The notion of knowing-in-practice approaches practice from a topological perspective. This spatial imagery positions practice as the place that ties the ‘knowing’ to the ‘doing’ (Corradi et al., 2010). Thus, instances of practice become instances of knowing (Nicolini, 2011). The verb ‘to know’ that is appropriated in the term ‘knowing-in-practice’ relates to how practitioners are ‘able to participate with the requisite competence in the complex web of relations among people, material artefacts and activities’ (Gherardi, 2009a, p. 118). Scholars who appropriate this perspective, like myself, identify a specific practice and then describe the activities that emerge from it. Oft-cited practice-based studies that have been conducted from a topological stance include flute-making (Yanow, 2003), the circulation of safety knowledge (Gherardi & Nicolini, 2000), and bridge-building (Suchman, 2000).

Feldman and Orlikowski (2011, p. 1243) also use the term “knowing-in-practice” and define it as “knowledgeability that is continually enacted through on-going action”. This emphasis on open-endedness is important for this study as it positions knowing as indeterminate and continually unfolding, and therefore practices can never be fully known in advance. This is relevant for considering education practices, because it is arguing that, from this perspective, knowing necessarily escapes methods of representation, and practices are impossible to formalise in advance of engaging with them.

Although knowing-in-practice has been taken up in many areas of scholarship, I draw attention to two studies, which work with knowing-in-practice. Firstly, Orlikoswki (2002) worked with the notion of knowing-in-practice to show how distributed organising – working effectively over multiple boundaries (e.g., temporal, geographic, political) – could be understood as an enacted collective capability, which was grounded in everyday practice. Studying practitioners' everyday work at Kappa, a large software company, she identified five practices that illuminated particular knowings-in-practice: sharing identity (knowing the organisation), interacting face-to-face (knowing the players in the field) aligning effort (knowing how to coordinate across time and space), learning by doing (knowing how to develop capabilities), and supporting participation (knowing how to innovate). Through engaging in these practices, practitioners at Kappa could collectively and "knowledgeably navigate and negotiate the multiple boundaries that they routinely encounter in their daily work" (p. 269) in order to enact distributed organising. This study is helpful to show how knowing is a collective endeavour that is constituted and reconstituted in everyday practice. Thus, knowing cannot be assumed as a stable property, only as an on-going achievement that is situated and distributed.

Knowing-in-practice is also a central tenet to Hager, Lee, and Reich's (2012) theorising of professional practice. Hager et al. (2012) coupled practice theory with workplace learning research to develop a framework for understanding professional learning. They proposed five principles for theorising practice, which includes understanding knowledge as a process of 'knowing-in-practice'. The other four principles situate practice as: a sociomaterial phenomenon; embodied and relational; evolving in historical and social contexts; and emergent. Although I am not using practice *theory* in this study, I have found using Hager et al.'s (2012) principles a helpful learning exercise during this doctoral study. In Chapter 4, I map their five principles on to a particular work activity emerging in the engineers' everyday work: obtaining a signature on a contract. In doing this, concepts that seemed complex and esoteric at the start of my study suddenly made a lot more sense when I could relate them empirically to the practices that I had observed unfolding at TurboUK.

The second study I draw on used this practice-theory framework to explore experienced engineers' learning in the construction industry (Reich et al., 2015; also discussed in Rooney, Willey, Gardner, Boud, Reich, & Fitzgerald, 2014). Using a site walk as an example of a practice, they showed that engineers' knowing was not 'applied' during a site walk, but was enacted through a collective and situated process, often with clients. This knowing-in-practice was shaped by the material arrangements of the site that changed and emerged daily in unpredictable ways, such as "vandalism, protective covers dislodged by wind, rainwater damage or ponding" (Reich et al., 2015, p. 373). Therefore, knowing-in-practice can be said to be concerned with the local, material and particular.

Before I further explore how I am working with knowing-in-practice, it is important to acknowledge how I am conceptualising the notion of 'learning', which is so intricately entangled with concepts of knowing.

Where is the learning in 'knowing-in-practice'?

The focus of this study is on exploring the knowings-in-practice emerging in the engineers' work as they enact competent knowing to balance and negotiate multiple tensions. There will, more than likely, be moments when engineers are faced with situations that they have not encountered before, or where the necessary conditions are not available to make well-informed decisions. In these moments, engineers must move from the familiar to the unfamiliar to enact competent knowing. It is in these spaces that learning may occur. In this sense, learning is performed not as a "set of dictates for proper practice" per se, but as "improvised practice" (Lave & Wenger, 1991, p. 93) that help refine local knowledge practices.

My second research question implies that 'learning strategies' are evoked to respond to these moments. As I delineated in Chapter 1, I understand learning strategies as enacted material practices, configuring new or different alignments between human and non-human actors in response to the tensions created by the complex demands on professionals' everyday work. Thus, as with knowing, I see learning emerging from these strategies as a sociomaterial effect; embedded in practices as a situated, embodied, practical and materially-mediated accomplishment (Fox, 2006; Gherardi, 2011). This sociomaterial approach considers learning, along with knowing, to be a process that is on-going, temporal and unable to be decided in advance (Hager, 2011).

However, the theoretical concepts I am working with in this thesis do not tend to refer to 'learning', but to knowing. For example, the title of Gherardi's (2001) article "From organizational learning to practice-based knowing" makes prominent this shifting focus from learning to knowing. As I will show later in this chapter, Actor-Network Theory scholars seem to avoid using the term 'learning', but would instead talk of knowledge-making processes. Therefore, while I approach 'learning' as being performed on a continuum with knowing-in-practice, where knowing and learning are mutually implicated, my focus in this study will be on *knowing.*

I now turn back to describing how I am working with the concept of knowing-in-practice. In the following subsections, I foreground three aspects of knowing-in-practice that are helpful for my analysis: an appreciation of the embodied and aesthetic dimensions of knowing, a focus on collective know-how, and a sensitivity to on-going mediation with material resources. While these three aspects are intricately entangled with each other, I have untangled them into three separate subsections to be able to explore them here in more detail.

Knowing-in-practice as embodied and aesthetic understanding

I was drawn to a knowing-in-practice approach as it accounts for embodied and aesthetic dimensions of knowing processes (Gherardi, 2011; Strati, 2003). From my own weekend adventures to a windfarm site, where I would watch engineers operating the towering cranes, I was struck by the corporeality and sensibilities involved in engineering work. Enormous turbine components would be lifted and then carefully lowered so that they aligned perfectly on top of each other, defying gusts of wind and jamming machinery parts (see Figure 2).

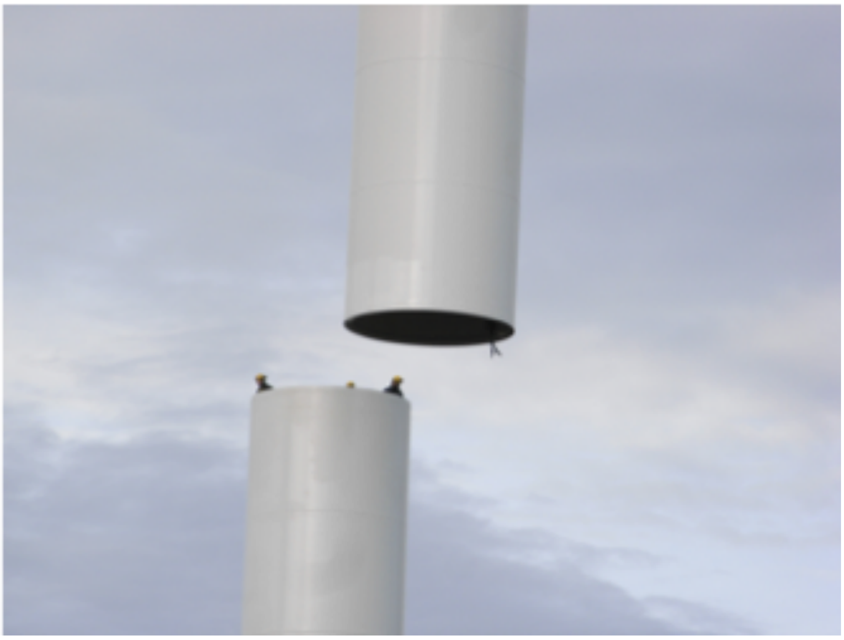


Figure 2: Aligning tower components on wind farm site

Inarguably, any person engaged in this scene could not fail to have their perceptual facilities mobilised by this activity. This sensible attunement to work practices can be termed ‘aesthetic knowledge’, which takes “due account of our knowing in practice, as experienced and supported by the senses rather than just the way we think” (Strati, 2003, p. 53).

Strati (2003) describes an opportunistic observation of three workmen quite literally dancing around on a two-story high roof removing tiles, with little regard for health and safety. Impressed with their dexterity and speed at completing their task without slipping and falling, Strati later asked the workmen how they remained so safe, speedy and efficient. They replied that it was “‘in feeling the roof with your feet’ and that they needed to ‘look with your ears’, because noise was a valuable source of information” (p. 60). This awareness of knowing how to do something, but which evades articulation and formal representation as ‘knowledge’, is termed ‘tacit understanding’, and is attributed to Polanyi (1966).

In a study on rock construction workers, Styhre (2009) showed how everyday knowing was embedded in aesthetic knowledge, where workers’ decisions were made through touching, seeing and hearing the material resources, combined with practical skills. For example, workers had to operate a rock spray machine to spray concrete onto underground walls. To technically control the machine was not too difficult, but to use it competently required an intimate knowledge of how the machine moved, listening for when the spray mouth-piece sounded like it was not working properly, and sensing when the pressure was too strong or too weak. Styhre (2009, p. 392) remarks that this practice embeds a high level of tacit knowledge “comprising sensual skills and attentiveness”.

In both Strati (2003) and Styhre’s (2009) studies, the senses – sight, hearing, smell, taste and touch – were implicated in the knowings-in-practice. However, while these stemmed from a personal sensorial capacity, knowing what constituted aesthetically pleasing practice was a socially and materially constructed knowing-in-practice, bound up in bodies and objects. This understanding is closely linked to what Kemmis (2009) would call embodied knowing, where the whole person and their body is engaged in practice, not just their cognitive capacities. In Reich et al.’s (2015) study, site walks involved the movement of bodies walking or driving over site, and engineers’ bodies travelled many miles to be present at a specific time and place to attend a design meeting reviews. In practice-based studies, aesthetic and embodied engagement could be termed as affective knowing (Gherardi, 2017b). Here, the word affect “points to the sensible, to the aesthetic knowledge that practitioners develop through their senses while working and becoming competent practitioners” (Gherardi, 2017b, p. 216).

These insights suggest that if knowing is bound up in action, through embodied and aesthetics ways, then practical knowledge should be considered to be as important as other forms of knowledge in education practices. Practical knowledge, often referred to as know-how, is considered in more detail in the next section.

Knowing-in-practice as collective know-how

A focus on knowing-in-practice helps to shift the focus of knowing from acquiring propositional knowledge, to practical know-how, which is inherent and inseparable from the action itself (Eraut, 1994). This ‘know-how’ was prominent in Orlikowski’s (2002) study. ‘Know-how’ originated from Ryle’s work (1949), who made the distinction between “knowing that” and “knowing how”. Brown and Duguid (1998, p. 91) adapted Ryle’s work to position ‘know-how’ against ‘know-what', where know-how is "the particular ability to put know-what into practice". Recognising that such distinctions between know-what/how could reify knowledge as discrete elements, Brown and Duguid (1998) emphasised the emergent nature of know-how by situating it as being embedded in particular communities of practice.

In this study, I look to this concept of know-how to explore how engineering practices may be enacted as 'acceptable', or not. Gherardri (2009b) argues that, for a practice to become meaningful, and to be continually and competently reproduced over and over again, constant negotiation of what constitutes a correct or incorrect mode of practising is played out within the community of its practitioners. Gherardi (2009b) also contends that ethical and aesthetic criteria shape a particular way of performing 'acceptable' practice. Some could argue that this is performed as *collective* know-how: the shared understanding and the rationalisation which support a particular professional community's way of practising. In Orlikowski's (2002, p. 267) study, this was demonstrated by the practitioners enacting the "Kappa way of doing things", which prompted a shared identity that delineated the boundaries of what was deemed appropriate in everyday practices.

However, this collective know-how seems to rely on a socio-cultural understanding of professional learning that foregrounds a community of practice (CoP) approach. It is at this point in my reading of knowing-in-practice that I encounter some shortfalls to CoP. Firstly, I find the notion of 'legitimate peripheral participation' a rather static idea, one that assumes newcomers learn social and cultural practices through apprentice-style learning from older colleagues. This is an issue for professionals working in emerging industries because, due to the relative newness of the industry, there is a lack of expertise from longer-serving employees who legitimise references to past knowledge practices.

Furthermore, Gherardi et al (1998) contend the notion of CoP promulgates a risk of reification in that it sets up a boundary around a particular group of people, suggesting the existence of a stable, harmonious and orderly 'social' object. I found that engineers' practices were constantly changing due to the high level of uncertainty in policies and rapid technological development. So, how can engineers in emerging industries learn from the ‘periphery’ if the practices and knowledge are yet to be developed, or are changing so rapidly they fail to stabilise? In fact, several scholars (Gherardri, 2009a; Roberts, 2006; Corradi et al., 2010) have recommended that the term ‘community of practice’ is better transposed as ‘practices of community’. That is, rather than a community existing *a priori*, containing the knowledge and determining the activities, the latter term foregrounds the activities as generating a community, which is precariously held together by people, relations and materials.

Furthermore, whilst ‘materials’ are often mentioned in practice literature, Styhre (2009) and Fenwick (2012), among others, emphasise that there has not been enough recognition of materiality in discussions of practice. This is the focus of my third, and final, aspect of knowing-in-practice.

Knowing-in-practice as an on-going, materially-mediated action

When I refer to *materially-mediated* action, I am implying that that processes of knowing cannot be untangled from the materialities that the enactment of knowing takes place in, and through (Law & Singleton, 2003). Svabo (2009) notes that practice-based language offers helpful vocabulary to describe social and material interactions in knowing processes. One word that I have found helpful for thinking about knowing-in-practice as on-going, materially-mediated action is ‘tinkering’.

In his study of rock construction workers, Styhre (2009) showed that to be able to practice competently and ‘make things work’, the workers “must always tinker with an assemblage of resources comprising technology, skills, tools, and standard operation procedures” (p. 387). He borrows the term ‘tinker’ from Timmermans and Berg (1997), who use it in their study of a medical protocol in a Dutch hospital. They talk of tinkering to denote the enacted flexibility to adapt the protocol to unpredictable events that emerge in everyday work. I work with the notion of ‘protocol’ in Chapter 5, which Timmermans and Berg (1997, p. 277) describe as a process intended “to detail what needs to be done when, by whom, and in what order”. They argue that working with standardised processes, such as protocols, is always an on-going accomplishment of tinkering.

In her study of a research process in a laboratory site, Knorr-Cetina (1979) uses the term 'tinkering' to denote a positive mode of operation that leads to successful solutions to problem-solving. She argues that it is through local idiosyncrasies and interpretations of codified rules, standards or processes that this tinkering 'know-how' is performed "to best make things work" (p. 359). Knorr-Cetina argues that this constant negotiation and manipulation of material resources is achieved through the manifestation of spaces that allow for ambiguity, slack, and contingency. Thus, tinkering recognises the situated, local and particular aspects of knowing-in-practice. However, citing Knorr-Cetina's (1979) study, Nespor (2011) highlights that, while tinkering may not be an illicit way of working, the failures, mistakes and trial-and-error attempts that characterise this practice, may be seen as insubordination or incompetence by employers or other colleagues.

Therefore, I define 'tinkering' as on-going, materially mediated action that is performed in ambiguous, opaque spaces, where what is unfolding from the action is a result of the 'same' practice being enacted amongst differing situations and exigencies. Furthermore, I argue that tinkering is an especially useful concept to draw on to investigate how practices are performed in instances of incomplete, or unknown information (Styhre, 2009), and in conditions characterised by uncertainty and volatility, which I have pointed out are characteristic of engineering work in Chapter 1.

In summary, I am drawing on Gherardi's (2001) notion of knowing-in-practice to position knowing as emerging in doing. In particular, I emphasise three aspects of knowing-in-practice: embodied and aesthetic engagement, or affective knowing; collective know-how, and on-going, materially-mediated action. I have shown how it is a useful concept to describe knowing as situated, which does not require investigation of what goes on in people's minds and of what they say that they think. Instead, it foregrounds what kind of social and material arrangements are being mobilised. Thus, this positioning of knowing-in-practice can be clearly read as a sociomaterial process.

However, I felt knowing-in-practice by itself was not sufficiently adequate to conceptually account for how materiality was implicated in engineers' knowing. I needed a complementary sociomaterial approach that would help show *how* knowings-in-practice emerged as situated, sociomaterial accomplishments, and what these knowings-in-practice looked like. Understanding how these knowings-in-practice were being performed, and what social and material conditions were implicated in these knowings, could provide helpful insights for how education practices might be assembled to account for the complex, ambiguous and uncertain demands unfolding in engineers' everyday work. Following Fenwick and Edwards' (2010, p. 1) approach to working with ANT in education, I am drawn to ANT not as "a way not for telling us about [or representing] educational issues; it is a way of intervening [or interrupting] in educational issues to reframe how we might enact and engage with them". I now turn to explore ANT in relation to my study.

Networks, relations and materiality: Actor-Network Theory

> [Actor-network theory's] point is not to finally, once and for all, catch reality as it really is. Instead, it is to make specific, surprising, so far unspoken events and situations visible, audible, sensible. It seeks to shift our understanding and to attune to reality differently … It opens up the possibility of seeing, hearing, sensing and then analyzing the social life of things – and thus of caring about, rather than neglecting them.
>
> Mol, 2010, p. 255

In this section, I show how the theoretical approach that I draw on to map unfolding knowings-in-practice recognises that the human is much more than human. Working with ANT, I aim to explore how engineers are considered as participants in networks of practices, and that particular knowings-in-practice emerge as an effect of these networks. While ANT is not a theory of learning, its unique philosophical stance foregrounds sociomaterial entanglements, complexities and taken-for-granted aspects of knowing and learning practices. Fenwick and Edwards (2013, p. 57) point out that ANT analyses of educational research show how the entities that are most likely to be the subject of inquiry, such as classrooms, virtual learning environments, policies, standardised assessments, curriculum and knowledge generation, are better understood as "gatherings of myriad things that order and govern educational practices". It is the latter entity, knowledge generation, which I am particularly concerned with exploring with an ANT analysis in this thesis.

Fenwick et al. (2011, p. 10) explain that knowledge generation in ANT comprises:

> a joint exercise of relational strategies within networks that are spread across time and space and performed through inanimate … as well as animate beings in precarious arrangements. Learning and knowing are performed in the process of assembling and maintaining these networks, as well as in the negotiations that occur at various nodes comprising a network.

Therefore, understanding the networks and flows that are circulating in workspaces can start to make visible how different knowings are produced through detailed interactions among people and the things of their practice.

ANT emerged from within Science and Technology Studies (STS) as a distinctive approach in the 1980s. STS acknowledges that scientific facts and technologies are not autonomous objects, but influence and, in turn, are influenced by, political systems, social relations, and human values. Humans are not necessarily as in control of their practices as they might think: non-human entities play a role in how practices are constituted and thus what knowings are achieved (Sørensen, 2009).

An ANT study takes as its starting point that the ‘real’ world is constituted through the particular and the local. As Mol (2010) alludes to in the above quote, reality is not something ‘out there’ to be captured by the scientist, but is repeatedly performed. This perspective is quite a radical disruption of conventional theories of sociology as, not only does it refute distinct categories and dichotomies, such as individual/community and subject/object, but it foregrounds the importance of things, or materials, in analysing social life. Materials that may be so deeply entrenched in the professionals’ routines that they are taken for granted, or ‘black-boxed’, by both the researcher and the professional who is interacting with them, are coaxed out of the ontological shadows imposed on the social by more traditional methods (Law, 2004).

Despite its increasing popularity and its proliferation into numerous disciplines besides sociology (including, education, cultural geography, organisation and management studies, anthropology, and tourism studies), Fenwick and Edwards (2010, p. ix) coach the ANT reader of the futility in defining ANT. They refer to

ANT as a virtual ‘cloud’, which is “continually moving, shrinking and stretching, dissolving in any attempt to grasp it firmly”. Many have argued that ANT cannot be considered a ‘theory’, because “[i]t offers no causal explanations and no consistent method” (Mol, 2010, p. 261). I look to Mol’s elegant summary to illustrate how I intend to draw from ANT as a sensibility (not a theory):

> For if ANT is a theory, then a “theory” is something that helps scholars to attune to the world, to see and hear and feel and taste it. Indeed, to appreciate it.
>
> Mol, 2002, p. 262

Perhaps, then, ANT is better understood as a sensibility or an approach. And not even as a single approach. Law (2007) argues that by offering multiple rebuttals to ANT critiques, one is accepting the stance that ANT is a singular rather than a multiple approach. Law (2007, p. 11) instead poses the question that “whether we really think that there is a single intellectual and political space to be ‘won’. Perhaps if we wash away this assumption we might conceive of theoretical intersections differently: as a set of possibly generative partial connections”. These new connections can be witnessed in the development of ANT as it passes through the hands of different scholars and disciplines, particularly in 1999, following Law and Hassard’s (1999) *Actor Network Theory and After* publication. This text bought together a collection of scholars to address criticisms levelled at earlier ANT writings that promoted a singular, rigid understanding of ‘network’.

I therefore look to Law’s (2007, p. 2) term “material semiotics” to describe ANT as part of a “disparate family of material-semiotic tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located”. This looser, more encompassing, definition reflects the shift towards more recent understandings of ANT, which account for multiplicity rather than singularity, and fluidity rather than rigidity.

To gain some purchase of what ANT can offer my analysis of engineers’ knowings-in-practice, I have looked to the work of French philosopher, Latour. His writings have helped me disrupt how I view both my, and other scholars’, ingrained assumptions that nature and culture exist and operate as separate domains. Whilst drawing heavily on Latour’s work, I am also layering my theoretical approach with concepts from other ANT and STS scholars. As Mol (2010, p. 261) would argue, I am “*linking up* with ANT … [to] learn sensitising terms, ways of asking questions and techniques for turning issues inside out or upside down” (emphasis mine). This linking up helps to disrupt socio-cultural and cognitive understandings of knowing and learning, and allows me to ask new questions that appreciate a more than human view of the social. I now move on to present key notions that are useful for this study, and which help map the knowings-in-practice emerging in engineers’ everyday work. I interweave some of the current critiques of ANT throughout this discussion, showing how more recent ANT writings on multiplicity and fluidity are helpful to analyse the findings of this study.

Sociology of association: ‘To follow the actors’

In his seminal book, *Science in Action: How to Follow Scientists and Engineers Through Society,* Latour (1987) questions the scientific production of knowledge, and argues that ‘facts’ are social constructs. He challenges the researcher to eschew categorical representations and, instead, to flatten the social by tracing the things that come together to perform particular knowledges, or ‘facts’ into existence. Latour (2005, p. 9) terms this view of the social as a “sociology of associations”, which is the “trail of *associations* between heterogeneous elements”. This view reframes the social, not as “a thing among things, like a black sheep among other white sheep, but a *type of connection* between things that are not themselves social” (p. 5, original emphasis). It is this emphasis on relationality between human and non-human entities, called ‘actors’ in ANT parlance, that is of particular interest in this study, as it helps to conceptualise how knowing is performed as a *relational* effect generated through the dynamic gatherings of heterogeneous entities.

Latour (2005, p. 71) defines an actor as “any thing that does modify a state of affairs by making a difference”. As already intimated, actors can be human or non-human. For example, in Reich et al.’s (2015, p. 375) study, they point out that the non-human ‘things’ (what I would now call ‘actors’) that mediate practice in engineers’ design review meetings were not only concrete entities such as laptops, Blackberries, iPads and work schedules, but abstract things such as "contractual relationships, regulations, [and] organisational procedures". Actors can be both passive and active, and move between these two states depending on the relations they are associating with in the network.

Latour (2005) uses the terms 'intermediary' and 'mediator' to denote the passive and active role of actors. I have found that Fenwick and Edwards (2010, p. 1) provide a helpful way to understand these concepts. They define an intermediary as an entity that "transports another force or meaning, without acting on it to change it", whilst a mediator "can transform, distort or modify the meaning in the elements it is to conduct" (2010, p. 1). Therefore, actors not only reshape other actors, but can be reshaped themselves. As Callon (1987) points out, an actor-network itself can be considered an actor tasked with gathering heterogeneous entities, whilst at the same time it can be considered as a network that can redefine and transmute what it is made of.

Understanding the work of these 'actors', and to "render associations traceable again" (Latour, 2005, p. 157) are motives that underpin Latour's (2005, p. 12) popularised maxim: "to follow the actors themselves". The idea behind this directive is to trace, in fairly detailed ways, the various human and non-human actors that come together that would have been backgrounded or omitted by any other method. I found this a useful directive to help challenge the received understanding of education as the world being learnt about through representation. One of the problems with representation, Latour (2005) argues, is that trying to explain social issues with yet more social categories will result in a failed logic. For example, when employers request that engineering graduates need 'communication skills', the social concept of 'communication' is now used so generically, it has been abstracted and separated from the material practices through which it is performed. For educators to understand how 'communication' is enacted, 'communication' needs explaining itself, and not just with another social substance which is likely to be an abstraction.

Latour (2005, p. 221) argues that we are too quick to reach for tropes and clichés to explain issues of the social: "social explanations have of late become too cheap, too automatic". He maintains that it is the researcher's job to turn to detailed description "to make sure that every entity has been reshuffled, redistributed, unravelled and 'de-socialized' so that the task of gathering them again can be made in earnest" (p. 221). Therefore, 'to follow the actor' would allow me to observe practices as they unfolded, and trace how 'communication' was being performed as a relational effect between human and non-human actors.

However, as a method, even Latour (2005, pp.121–122) recognises the total impracticality of following the actors:

> How ridiculous is it to claim that inquirers should 'follow the actors themselves', when the actors to be followed swarm in all directions like a bee's nest disturbed by a wayward child? Which actor should be chosen? Which one should be followed and for how long? And if each actor is made of another bee's nest swarming in all directions and it goes in indefinitely, then when the hell are we supposed to stop?

Law (1991) highlights that critics of Latour's directive 'to follow the actors themselves' have expressed concern that, as the researcher starts to see the world through the eyes of their participants, they lose the critical distance necessary to flatten the social. Consequently, the researcher begins to take on the categories of their participants. This makes other actors invisible as they, "tend to melt from view" (Law, 1991, p. 11). Therefore, how does a researcher retain a critical distance? In the next two sections, I present two concepts that encourage a critical approach to flattening the social: inviting 'matters of fact' to be considered as 'matters of concern' (Latour, 2004) and acknowledging presence and absence (Law, 2004).

Inviting 'matters of concern'

One approach towards criticality can be taken by questioning how knowledges are produced, circulated and embedded as 'matters of fact' by reopening them as 'matters of concern' (Latour, 2004). Latour (2004) uses the terms 'matters of fact' and 'matters of concern' to define our attachment to 'things'. When a thing is viewed as a 'matter of fact', it becomes a "'cold' stable object" (Latour, 1987, p. 21). It has been black-boxed. Latour (1987, pp. 2–3) explains that the term "blackbox" comes from cybernetician vocabulary. In a situation where the cybernetician does not need to know what goes on at a certain catalytic point in a chain of commands as it is too complex to engage with, or irrelevant to the project at hand, the cybernetician would add a depiction of a little black-box to the network diagram. This symbolic lieutenant signifies that it is only the input and output that needs our attention: what is held in this black box, no matter how essential, complex or intricate the historical networks are that make it work, are 'boxed up'; hidden from view. The focus is shifted to what is produced by this black box, with no critical questioning on how it is produced.

When things are considered as matters of concern, objects are treated as 'things' again: as "'warmer' and unstable ones" (Latour, 1987, p. 21). The relations, gatherings and attachments that perform a 'thing' are foregrounded so that their controversies and uncertainties can be exposed and traced. Therefore, Latour (2005, p. 261) contends that ANT's "distinctive touch is simply to highlight the stabilizing mechanisms so that the premature transformation of matters of concern into matters of fact is counteracted". This is a useful concept for me as a researcher, to remind me to approach objects that engineers may take for granted and open-up these black-boxes by asking questions in interviews, or by taking photos, for further exploration. It will also help me attune to moments when engineers were questioning their own work activities: when did they treat objects as matters of fact, and when did they stop to 'open it up': to tinker, disrupt, experiment?

Considering 'things' as matters of concern is also a useful concept to inform education practices, as, firstly, it is asking educators, students and practitioners to consider the material effects of everyday objects. Secondly, in the unfolding of the relations that are gathered to perform an 'object', networks of power can be revealed, which may be producing and reproducing issues of inequality. Therefore, if education practices focus on how to interrupt and agitate 'matters of fact', then learning can shift from "preparation and acquisition of competency to learning as attunement, response and even interruption" (Fenwick, 2015, p. 91).

Acknowledging presence and absence

Teasing apart issues of representation, Law (2004) writes about the enactment of presence and absence in research. Law argues that the researcher must be reflexive and acknowledge that what is being represented is never a direct action, but is always mediated. This mediation that brings something ‘in-here’ will always make absent something ‘out-there’: “*what is being made present always depends on what is also being made absent*” (Law, 2004, p. 83, original emphasis). Law describes two types of absence. ‘Manifest absence’ is when the thing that is in non-attendance is explicitly acknowledged to be absent, for example, it is noticed by the researcher but bracketed out. The second absence is an inescapable activity for researchers. This is ‘Othering’, and refers to absences that go unnoticed and unacknowledged by the researcher because they are so mundane or routine that they are over-looked, or repressed. This is similar to the process described by Latour’s (1987) concept of ‘black box’. Working with ANT concepts allowed me to work with a slower, more flexible method, that directed my attention to what was being Othered. This was useful to remain critical as a researcher, and to attune to how actors (both human and non-human) enrolled in engineering work at TurboUK may be enacting Othering.

In the next subsections, I explore in more detail the ANT concepts that account for what unfolds when different actors come together, and introduce four important terms that I work within this thesis: translation, obligatory passage point, network, and assemblage.

Translation and obligatory passage points

Translation is the term used in ANT to describe what happens when different actors (human and non-human) are gathered together and then change each other in a process of association, or connection. A principle account of an ANT case study that explores how translation is achieved was provided by Callon’s (1986a, p. 81) “sociology of translation”, which shows that “translation is a process before it is a result”. In exploring an experimental technology for scallop fishing in St Brieuc Bay, Callon (1986a) articulates four moments of translation:

problematization, interresement, enrolment, and mobilization. These four stages of translation are briefly summarised as follows.

Firstly, specific actors (e.g., clients, government policies, local council members) may have agendas that they want to advance. At this first stage of translation (problematization), a specific actor identifies other actors it wishes to align interests with, and sets about channelling these actors through their domain, positioning the specific actor as indispensable (Callon, 1986a). This network channel is called an ‘obligatory passage point’ (OPP). Through this process, the specific actor tries to interest and mobilise other actors, some who may be resisting this enrolment. If successfully enrolled, social agendas are folded into material artefacts, for example, into databases and processes, delegating the social relations to a technology and “prescribe[ing] back to the users the values and structures they were built to enforce” (Latour, 1986, p. 310). This is known as ‘inscription’, where the technical artefact ensures the protection of an actor’s interests (Latour, 1992). Such technical artefacts are forces that are mobilised to strengthen the network. Once a network becomes stabilised, Latour (1987) might say that it is performing as an immutable mobile: it can move around whilst still holding its shape, and perform action at a distance. All the negotiations and tensions that brought it into existence are smoothed over and made invisible. However, this only works for as long as the succession of complex relations are held in place. The stability of an actor-network is always precarious and may be undone in an instant.

Whilst this reading of translation has helped my understanding of ANT, Adams and Thompson (2016) highlight that it is possible to work with the notion of translation without traversing through each of these four moments, although I do draw on the notion of OPP to describe some aspects of the engineers’ practice. Instead, I work with translation as an analytical concept that helps show how particular knowings-in-practice emerge as sociomaterial effects by focusing on what happens at each of the micro-connections between various actors that have been assembled together in what appears to be an immutable object, for example, a contract, an organising process or a new technology.

Gathering metaphors

Latour (2005, p. 132) maintains that we need a word to describe these “flows of translations”, which is designated to the term ‘network’. Latour (1999a) opted for the word ‘network’, as he later argued, purely for lack of a more fitting word and because it was already attached to the word ‘actor’. However, Sørensen (2009) points out that the term ‘network’ conveys the imagery of a stable, all-encompassing and settled gathering. Nevertheless, Latour (2010a, p. 5) continues to defend his use of ‘network’. He argues that he uses the word “not simply to designate things in the world that have the shape of a net … but mainly to designate a mode of inquiry that learns to list, at the occasion of a trial, the unexpected beings necessary for any entity to exist”. ‘Network’, in this sense, does not exist as a ‘thing’ out there, but acts as “a tool to describe something, not what is being described” (Latour, 2005, p. 131).

However, Latour (1999a) does acknowledge that the increasingly popularised uptake of ANT was contributing to the reification of the term ‘network’ in Actor-*Network*, and, in *Reassembling the Social* (2005, p. 2), he began playing with the notion of ‘assemblage’ to denote the more messy, fluid and dynamic essence of ANT. Law (2004) draws attention to the notion of assemblage as an imperfect translation of the French term *agencement*, from Deleuze and Guattari’s (1987) work. That is, the English term ‘assemblage’ may be mistaken as meaning a clear and rational “state of affairs” (Law, 2004, p. 41), rather than uncertain, tentative and unfolding processes, which is the meaning of *agencement.* Keeping this tentativeness in mind, I find ‘assemblage’ perhaps a more fitting metaphor to use in this study, as it reflects the unfolding and uncertain nature of knowing-in-practice, which eludes any “fixed formula” (Law, 2004, p. 42) or representation. However, I will use this term ‘assemblage’ and ‘network’ interchangeably when describing the dynamic gathering of heterogeneous bits and pieces.

Whilst ANT research strives to treat humans and non-human entities in the same way in these networks, some scholars have criticised ANT as being too fixated on centring a powerful, heroic figure (often an innovator or engineer) at the centre of an ANT case. It is this powerful figure who attempts to enrol other actors through the “funnelling interessement” (Star & Griesemer, 1989, p. 390) of a single obligatory passage point. The next section considers this critique, and introduces notions of ordering, performativity and multiplicity, which I take up in my study to help address this issue.

Ordering, performativity and multiplicity

In response to the criticism that obligatory passage points promote single moments of translation, Law (1994) and Mol (2010) suggest that the term ‘modes of ordering’ may be a more helpful term than ‘translation’ to denote a relational ontology. The plural of the word ‘mode’ signals that, in any given time or place, there are multiple ‘modes’ being *performed*. I draw attention to the verb ‘performed’ here to show that the active notion of performativity is a crucial feature of a relational ontology where “different elements assemble together and act in certain ways to produce specific consequences” (Law & Singleton, 2000, p. 774). Law and Singleton (2000) state that these hybrid performances need to be enacted. This suggests a *doing*: an accomplishment or an achievement. I use both the verbs ‘perform’ and ‘enact’ throughout this thesis to denote this sense of ‘doing’ a reality.

A key feature of performativity that is pertinent for this study is that the work to assemble these performances is *on-going*. That is, vast amounts of energy are expended by different actors in trying to maintain the connections that act in certain ways. Nothing is ever in a finished, final state, but is constantly performed in the moment: “There is no social order. Rather, there are endless attempts at order*ing*” (Law, 1994, p. 101). Organising practices, knowledges and objects are effects of these endless attempts at ordering. They are being *performed* into existence.

I have found Latour’s (1986) ‘ostensive’ and ‘performative’ views of reality useful to keep in mind when working with the concept of performativity. An ostensive view assumes that the social is characterised by stability, predictability and orderliness, which is treated “in principle” (p. 272). Yet, “in practice”, the social is better understood as being performed, and is in fact unstable and fragile, a “negotiable, a practical and revisable matter” (Latour, 1986, p.264). Thus, the performance of the social is subject to translation, depending on the hands through which it travelled and the networks within which it was located. Therefore, a performative understanding helps to reconceptualise knowing as an on-going process that is enacted, in the moment, by the actors themselves rather than being understood as a reified ‘thing’, contained in, and imposed upon, the engineers. This is an important concept to highlight as it opens-up a different way of understanding how ‘acceptable practices’ and ‘innovation’ might be seen, in Law’s (1994) terms, as ‘endless attempts at ordering’, which are enacted as performative, rather than ostensive, knowings-in-practice.

The notion of performativity helps address a critique of ANT that it is politically conservative and fails to offer explanations in favour of description (Whittle & Spicer, 2008). Law and Singleton (2000, p. 767) point out that ANT is more than just description; the very act of writing an account is a political performance, which produces its own reality “that does equally particular kinds of work”. Thus, I am conscious that, in the writing of this thesis, I am performing a certain political reality that could be otherwise. I reflect on this performativity in further detail in the following chapter, and in Chapter 8.

Furthermore, Law (2009, p. 151) reveals that this shift to a performative ontology has “strange consequences”. By this, he means that alongside multiple modes of ordering emerge multiple *realities.* This is quite a move from claiming that there are different perspectives of a single reality. It signals a shift from “epistemology and representation to practical ontology and performativity” (Jensen, 2010, p. 7). Mol (2002) is often attributed with this revelation. In her study of lower limb atherosclerosis practices, Mol (2002) contends that atherosclerosis, as a condition, emerges in different forms and in different places. For example, in the doctor’s surgery it is performed as painful walking, while in hospital it is performed through X-rays and radiography as blocked blood vessels. The different material and local practices evoke their own material reality: “in theory the body may be *single*, but in practice it is *multiple* because there are many body practices and therefore many bodies” (Law, 2009, p. 152, original emphasis). Law (2007) argues that in acknowledging that there are multiple actor-networks circulating, the demand for a centre (for example, a single OPP) has disappeared. Therefore, an 'object' or a 'knowledge' that appears to be one thing may be understood as multiple; as "a set of related performances" (Law & Singleton, 2000, p. 775).

This understanding of multiplicity has truly been a revelation for how I have come to understand practice because, as a researcher, I no longer feel obligated to look for neat, ordered and coherent patterns to 'explain' certain phenomena. It allows me to approach the engineers' practices as messy, ambiguous, and indeed, multiple performances that are "irreducible to one another" (Law, 2007, p. 14). I return later in the chapter to the notion of multiplicity, highlighting how it has helped me to conceptualise the mediating role of objects in engineers' practices.

As I imagined I would see lots of different modes of ordering that were being performed, perhaps as multiple realities, as the engineers worked together to sell, and build-out, wind turbines, amongst high levels of change and multiple actors, I needed to consider how I would conceptualise these 'orderings'. While 'assemblage' and 'network' are useful metaphors to help describe the tentative gathering of different bits and pieces, I needed a concept that helped me to understand *how* these different orderings may come together – and hold together, however briefly – to form connections that produced particular effects, such as policies, processes and technologies. To do so, I look to Law's (1987) concept of 'heterogeneous engineering', which I explore in the following section.

Engineering practice as 'heterogeneous engineering'

In this section, I discuss the origin of Law's (1987) 'heterogeneous engineering' concept to show how engineering practice can be understood as a complex sociotechnical activity, rather than a bounded, technical achievement (Trevelyan, 2014). However, I go on to show that, while this concept has been usefully appropriated by several engineering studies, a focus on the notions of fluidity and in/stability can further discussions around this concept, which is helpful for this study.

Law (1987) coined the term 'heterogeneous engineering' to describe how Portuguese navigators achieved technological and commercial supremacy in the 15th and 16th centuries. Law claims that the success of the Portuguese mariners in finding a solution to successful trading in Africa without succumbing to the fear of no return from Cape Bojador was through the alignment of a "*network* of juxtaposed components" (1987, p. 113, original emphasis). This network was a combination of social and technical engineering that enrolled and translated documents (such as an astronomical table), devices (the astrolabe and magnetic compass), and drilled people (trained in the reading and interpretation of documents and use of sophisticated instruments) to overcome "an environment filled with indifferent or hostile actors" (Law, 1987, p. 111), such as strong winds and treacherous seas, and political and economic factors. It was this precarious alignment that he termed 'heterogeneous engineering'.

As mentioned in Chapter 1, Suchman (2000) worked with the concept of heterogeneous engineering to explore how the work of engineering in bridge-building was performed as "knowing and acting from particular positionings at particular times, within a network of relations that must be simultaneously elaborated and contained" (Suchman, 2000, p. 312). She highlighted that engineering work was not merely the simple implementation of engineering technical knowledge, but was about making persuasive arguments to secure different interests. These persuasive practices were assembled through sociomaterial enactments of embodied performances, visual representations and particular discursive practices.

Williams and Figueiredo (2014, p. 181) also worked with the notion of "heterogeneous engineering" to show how junior engineers' work was a complex mix of technical and social interactions, which was at odds with their understandings of engineering when they emerged from pre-service education. They argued that novice engineers were taught to evaluate that the underlying reasons why something was, or was not, possible in engineering work was due entirely to the principles of engineering sciences. Williams and Figueiredo (2014) offer a framework that delineates the key actors that influence engineering practices, which include client needs, budget constraints, firm and reputational capital, as well as instruments and technology. They argue that while it is not a representational model of contemporary engineering, it could be used as a visual aid to help engineering educators support students in their transition to practitioners. This framework is similar to the relational map that I invited the participants to draw in this study, where the participants are asked to map the different ‘things’ involved in their everyday work (see p. 83).

However, while Williams and Figueiredo’s (2014) model shows social and technical interactions, I argue that it limits the connectedness between the actors as a two-way (sometimes even one-way) interaction. This does not account for the complexity and co-constitutive entanglements of a sociomaterial understanding of engineering practice. Therefore, in this study, I am interested in exploring in more detail what was happening during the processes of ‘heterogeneous engineering’ as multiple and distributed sociomaterial performances, and where instances of knowing emerged as on-going material, practical and situated accomplishments. This is the focus of Chapter 6.

Furthermore, Sørensen (2009) raises concerns about ‘heterogeneous engineering’ in her ethnographic study of school children’s participation in two online 3D virtual environments. Sørensen (2009) pointed out that the network imagery presented in ‘heterogeneous engineering’ did not quite fit with what she was observing in one of the projects, which she called ‘Femtedit’. She argues that in Law’s (1987) account of heterogeneous engineering, the success of the Portuguese’s mission was achieved through the stability of the network: if one component had resisted enrolment, or dropped away, then the network would have failed. However, Sørensen (2009) showed that Femtedit could still function if a component stopped working or was exchanged for another. The network did not have to be completely stable, in the sense that it was rigid, but could be invariantly and gradually transformed through shifting and incomplete associations. Sørensen concludes that that Femtedit was acting as a fluid object, one that could perform multiple realities. Thus, Sørenson’s findings show that heterogeneous engineering can still be accomplished amongst instability and shifting, or missing, components, if the notion of *fluidity* is bough into focus. The next section explores fluidity in more detail, in relation to in/stability, and how these notions relate to this study.

Fluidity and in/stability

Drawing on her findings of Femtedit's performance, Sørensen (2009, p. 77) points out that "stability in fluidity is not generated by fixed relations – as in network – but by continuous mutation". Thus, stability resides in material heterogeneity – in 'bits and pieces' – and these achieve significance in relation to others. This notion of fluidity is beautifully demonstrated in de Laet and Mol's (2000) case study of the Zimbabwean bush pump. In showing how a simple yet effective water pump becomes entangled in various networks in different Zimbabwean villages, de Laet and Mol argue that that the boundaries of the pump are not rigid and set, but are mutable. That is, if one element of the network does fall away, the network is not disrupted, but transformed. Bolts can be lost, valves removed and leather seals replaced and still the pump acts as a water pump. Because of its on-going adaption and fluidity, it is "not clear *when* exactly the Pump stops acting, when it achieves its aims" (p. 227). Similar to Sørensen's (2009) Femtedit, the bush pump was performing as a fluid object.

This on-going adaption and fluidity links back to the notion of tinkering that I introduced earlier, where processes, objects and technologies incrementally shift and shape practice as well as being shaped by practice themselves. Here, I am reminded of how Mol (2010, p. 265) uses the term "tinkering" to talk about how an object, technology or technique can be *fluidly* adapted through this "persistent activity done bit by bit, one step after another, without an overall plan". The notion of fluidity is useful for thinking about knowing-in-practice as it suggests that everyday practices may be interwoven with ambiguous and opaque spaces that could encourage fluidity and flow, which allow for constant flux and multiple realities to circulate.

Fluidity is also useful to think about performing stability. 'Performing' stability infers, at all times, the possibility of instability; of precariousness. Achieving stability of human and non-human networks was the main concern of Suchman's (2000) story of bridge-building. For example, the project engineers tasked with building the bridge were immersed in activities of professional practice, which gathered together actors such as timelines, budgets and technical components. Residents, on the other hand, were orientating along a different stabilisation trajectory, or mode of ordering. They were enrolled in a network of property prices, disruption and changing landscapes. These stabilisation trajectories shared only partially over-lapping fields, and thus residents and project engineers were almost competing to stabilise their own assemblages and thus further their own interests. I argue that it is in these spaces where the over-lapping trajectories meet that the notion of fluidity is key for affording the performance of negotiation, conflict, and compromise.

In the previous chapter, I have argued that there are many social, economic, political, and cultural forces that shape the engineers' practices in an emerging industry. Similar to Suchman's (2000) study, the competing stabilisation trajectories of different networks could threaten the engineers work to successfully sell TurboUK turbines and build wind farms. Notions of in/stability are key to this thesis because I want to show that it is from amidst the huge effort of aligning and maintaining certain assemblages, and negotiating, challenging, or balancing competing actor-networks, that knowings-in-practice and learning strategies emerge. Finally, this networked understanding of in/stability is useful for a sociomaterial study because it helps highlight how power is performed as an effect of stabilising heterogeneous entities, rather than something that is an inherent property of a single actor.

Power relations and the mediating role of objects

In this section, I show how power as a relational effect is a helpful perspective to show how the shifting role of objects mediate knowing practices. I find Latour's (1986, p. 273) "vague notion of power" helpful to conceptualise how networks of power are disturbed through different ways of ordering. From this perspective, no actor inherently holds more power, knowledge or complexity than the other; it is only through the different connections, or associations, between actors that effects such as power, knowledge and complexity are produced. However, as Feldman and Orlikowski (2011, p. 1242) remind the sociomaterial analyst, "relations of mutual constitution do not imply equal relations. Rather they are relations of power, laden with asymmetrical capacities for action, differential access to resources, and conflicting interests and norms".

From this perspective, issues of power can be understood as continuously circulating throughout everyday work practices as an organisational dynamic, even through taken-for-granted or mundane activities. This is apparent in Suchman's (2000) study, where she shows how engineers and residents were competing to stabilise their own interests and norms, though different ways of ordering, or stabilising trajectories. Thus, I understand power relations as being constitutively entangled in the sociomaterial assemblages that shape knowings-in-practice. This insight is important for this study because I want to show how different objects can generate force, and effects of power, when they are mobilised in different ways, in different networks.

As stated in Chapter 1, I am using the word 'object' to discuss the materials of the engineers' practices (such as telephones, laptops, processes) as this is how the engineers would normally view these entities. However, I am approaching objects as complex sociomaterial gatherings – as 'things' – that recognise their relational performance. In fact, I am approaching them as 'messy objects'. These are objects that necessarily evade thorough exploration by researchers due to their inherent complexity (Law & Singleton, 2005). For example, Fenwick and Edwards (2011) approached educational policy as a 'messy object'. Using ANT, they showed how educational policy is enacted in multiple, complex ways that slip through most theoretical and methodical interrogation methods. They argue that, by approaching educational policy as a messy, incoherent assemblage, constituted of "a series of precarious connections that enroll particular texts, behaviors, and values" (p. 726), rather than a singular entity, policy analysts may be better able to locate possible points for productive intervention.

In this study, I contend that a multiple theoretical approach is necessary when researching what some call 'messy objects'. I take this lead from Nicolini et al.'s (2012) study, who argue for the use of multiple theoretical perspectives to understand the different roles of objects in cross-disciplinary collaboration. I exemplify this approach in Chapter 4, where I explore how a signed contract began to work in many different ways, the full range of which would be impossible for me to account for as researcher. In the next two subsections, I introduce two theoretical approaches that I draw on to explore the mediating role of objects in knowledgeable practices: boundary objects and fluid objects.

Boundary objects and fluid objects: Different perspectives, or different realities?

Star and Griesemer (1989) coined the term ‘boundary object’ to explain how non-human actors can generate interpretive flexibility in coordinating activities across different social worlds. In their study of a natural history museum, they showed how various actors that shared the same objectives (promoting the protection of flora and fauna species) succeeded in co-operating over 30 years, despite competing and divergent perspectives. Objects, such as field notes, specimens and maps, became a focal point that allowed actors to maintain a plurality of perspectives yet still achieve progress. In this sense, boundary objects “are both plastic enough to adapt to local needs and the constraints of several parties employing them, yet robust enough to maintain a common identity across sites” (Star & Griesemer, 1989, p. 393).

I was attracted to the boundary object concept as I could see how useful it could be for analysing knowings-in-practice in an industry that was characterised by project work, shifting power relations, and the need to align different perspectives. For example, Bechky (2003) worked with boundary objects to show how two objects, engineering drawings, and machines, not only mediated problem-solving between three different occupational groups in a manufacturing firm, they also served to strengthen issues of power, through what she terms ‘occupational jurisdiction’.

However, it is important to point out that the concept of a boundary object originates from a different theoretical tradition (symbolic interactionism) than that of ANT, and is concerned with theorising how those from several social worlds align cognitively to make sense of a given situation. Nonetheless, several ANT researchers have realised the value in adopting it as an analytical concept to foreground the role of objects in organising work. For example, Sage, Dainty, and Brookes (2010) found that treating the project file as a boundary object could help coordinate a network of relations constructing the ‘thing’. Yakura (2002) studied timelines as temporal boundary objects to show that 'time' could be rendered visible and concrete, which allowed actors from various groups to negotiate and coordinate their activities. Koskinen and Makinen (2009) looked specifically at the role of boundary objects in negotiations of project contracts.

In Chapter 4, I work with the boundary object concept to show how a pre-signed contract mediated different perspectives and tensions. However, I reveal that once the contract was signed, it began to do different work. At that point, I found it useful to work with another theoretical perspective that conceptualised the signature (signed contract) as a *fluid object* (Law & Singleton, 2005).

Law and Singleton (2005) argue that while Mol (2002) could have considered atherosclerosis as a boundary object, this did not reflect what was unfolding in her observations at the hospital. A relational approach, rather than a symbolic interactionist perspective, could show that atherosclerosis, like the bush pump and Femtedit, was acting as a fluid object. However, it was a fluid object that was enacting not just different perspectives, but different realities. Thus, the point I wish to make here is one of ontological multiplicity. That is, objects can enact multiple realities. I argue that this ontological understanding of the mediating role of objects, coupled with boundary object concept, is helpful to understand the effects of a 'messy object', like the signature.

Chapter summary

In this chapter I have explored how I am drawing on knowing-in-practice and ANT as theoretical resources to inform my study. The concept of knowing-in-practice positions knowing as situated, collective, embodied, and materially-mediated, on-going action. ANT concepts provide a relational, networked understanding of *how* particular knowings-in-practice emerge in everyday work. Specifically, I focus on notions of translation and assembling, performativity and fluidity, and the mediating role of objects as insightful concepts. This relational approach disrupts traditional educational epistemologies, which tend to focus on representation, and narrow and rigid methods of investigation. In the following chapter, I explore how this theory has inspired my methodological approach.

Chapter 3: Generating a methodological strategy

This chapter discusses the methodological and analytical strategies that I drew on to present a practice-based, sociomaterial study of engineers' knowings-in-practice that are mobilised when working in an emerging, volatile industry.

In this chapter, I will outline the research setting and present the research strategy, including the methodological tools I worked with to generate data. Here, I describe how I negotiated access to a single setting as a case, an organisation based in a Scottish city, called TurboUK.[7] I discuss issues of access and time spent as an ethnographer in an organisation. I address ethical and legal concerns, including participant consent. I outline the recruitment process and detail the demographics of the voluntary participants. I present the multiple methods of data collection that I adopted to try to tease out the complexity and messiness of engineers' practices.

I then turn to discuss the effect I had on the research process as a participant observer in an ethnographic study, and how I attuned to issues of representation, positionality and reflexivity. I go on to eschew positivist notions of validity and reliability in favour of notions of trustworthiness and rigour to defend the strengths of my research strategy. Finally, I explore the analytical strategy I developed, drawing on descriptive textual accounts, or stories, of how particular knowings-in-practice were being performed in engineers' everyday work.

Drawing on an ethnographic methodology

In the previous chapters, I have illustrated how a practice-based perspective of professional work regards knowing and doing as being inextricably linked. Thus, if I wanted to better understand engineers' knowing, it follows that I needed to gain an insight into their ways of *doing*. Consequently, I needed to work with a methodology that would allow me to observe the engineers' doings *in situ*, and ask questions, over an extended period of time. Thus, an ethnographic approach,

[7] TurboUK is a pseudonym.

which encouraged an emergent, in-depth exploration of a particular setting, seemed a suitable methodology to adopt.

An ethnographic methodology catapults the researcher into on-going social and cultural activities of an individual, community or organisation (Neyland, 2008). Engaging in an ethnographic study is about “seeing, hearing, noticing, sensing, smelling, and then raking over what has been noticed, and trying to make some sense out of it” (Law, 1994, p. 50). To achieve this, the researcher may gather data through an extended immersion in a specific setting, often termed “fieldwork” (Van Maanen, 2011, p. 219). This fieldwork is likely to include adopting such methodological strategies as observing, listening, asking questions, and taking detailed notes.

Ethnography is a particularly useful methodology to start questioning some of the taken-for-granted, back-grounded aspects of everyday practices because it invites the researcher into the “subjacent realm”. This is a realm, as proposed by Schatzberg (2008, p. 24), where one can make “visible the invisible, convert silence to sound”, start questioning the unquestioned, and unearth the politics of practising at the everyday level. Therefore, ethnographic methods lend themselves to an ANT approach because they provide the time and space for the researcher to focus on the specific and local micro-practices of work, which are often messy, complex and slippery.

Pink (2007, p. 22) stresses that ethnography “does not claim to produce an objective or truthful account of reality, but should aim to offer versions of the ethnographer’s experiences of reality that are as loyal as possible to the context, negotiations and intersubjectivities through which the knowledge was produced”. This perspective is supportive of Law’s (2004) shift in understanding methods as not being a set of procedures set out to “*discover* and depict realities. Instead, it is that they participate in the *enactment* of those realities” (p. 45, original emphasis). That is, it is through the methods chosen by the social scientist that the reality they then write about is constructed. Following this, Whatmore (2003) looks to ethnography as the most sympathetic method in the social sciences and makes the distinction between ‘generating materials’ rather than ‘collecting data’: “Data emerge here not as nuggets of the ‘real world’, or as so many ‘discursive constructs', but rather as intermediaries or 'third' parties between researchers and researched that are as material as they are meaningful" (p. 87). Whilst I will continue to use the word 'data' in this thesis, I acknowledge Whatmore's insight that 'data' are materially generated.

A collection of ANT-inspired studies exploring issues of professional engineering work have drawn heavily on ethnographic methods, ranging from early ANT studies, such as Callon's (1986b) electrical vehicle and Law and Callon's (1988) military aircraft project, to the more recent engineering studies of a project file in construction project management (Sage et al., 2010) and a sustainable structural engineering project (Chilvers & Bell, 2014). These studies work with a single, empirical case, and I also chose a single case to explore engineers' everyday practice in an emerging industry.

To address the research questions that guided this study (see page 11), I developed an ethnographic strategy to "orient the study" (Neyland, 2008, p. 12). This was a fluid, "approximate strategy", which was "available for constant consideration, challenge and adaptation" as the study progressed (Neyland, 2008, p. 12). Thus, an ethnographic method can be termed as iterative-inductive research (O'Reilly, 2005).

In brief, my ethnographic strategy consisted of observing, following, listening and talking with 13 engineers who had voluntarily consented to participate in the study. I scheduled three semi-structured interviews with each participant. I attended meetings with the engineers, and observed them as they worked at their desks or in meeting rooms. I also completed a 'daily report' as a strategy to structure my written observations, the format of which I developed with respect to the emergent and iterative-inductive quality of the data.

However, when designing the research strategy, I was aware that the anthropological origins of ethnography, and their respective methods, tended to privilege human perceptions and cultural influences. For example, I found that traditional research interview designs struggled to elicit the material aspects of practice. Hammersley and Atkinson (2007) stress that ethnographic research needs to incorporate material *things* into "the fabric of ethnographic inquiry" as "the performance of work involves a sustained engagement with material means" (p. 137). However, an ANT approach, with its principle of general symmetry (Latour, 1993), would contest that empirical research warrants more than a 'sustained engagement' with materiality, and should treat social and material phenomena on the same terms. After all, as Latour (2005, p. 72) insists:

> ANT is not the empty claim that objects do things 'instead' of human actors: it simply says that no science of the social can even begin if the question of who and what participates in the action is not first of all thoroughly explored, even though it might mean letting elements in which, for lack of a better term, we would call non-human.

Therefore, as I was interested in exploring a sociomaterial perspective of knowing, I also wanted to be able to foreground the materiality of engineering practice. I adopted three visual and creative exercises to encourage participants to articulate, or make present, their relationships with the objects of their workplace. As explained, although I may attend to (and use the term) the 'object', I am still attuning to the thingness; to the relationality of the object (Adams & Thompson, 2016). I used one of these methods in each of the three semi-structured interviews: a relational map exercise, the "Interview to the Double" (Nicolini, 2009), and a photo-elicitation interview (Collier Jr, 1957). I also followed human and non-human interactions during day-to-day work. I will explore these methodological strategies in further detail throughout this chapter.

Shaping the research setting

Before I could begin to gather data, I needed to negotiate the boundaries that would define the research setting. The next section discusses how I approached an organisation within the wind energy industry, and how I negotiated my entrance and length of stay as a visiting ethnographer.

Negotiating access and length of stay

Working with an organisation or community to establish a space that could act as a research setting is a reciprocal accomplishment. The research setting was not just 'out there', ready to be entered, but was brought into existence through negotiations between a potential organisation and myself. I believe that researchers should approach a prospective research setting as though they were to be 'hosted'. This terminology implies a tentative relationship built on trust, manners and respect, and, as a guest, I would defer to the hosts' availability and wishes. To advance this tentative relationship and secure a successful host, I needed to negotiate two requirements: establishing access to the organisation in the first place; and then agreeing the length of time that I would be hosted.

Securing a host organisation

Smith (2001) reports that obtaining unrestricted access to an organisational work site is challenging and has taken some researchers over a year to negotiate. Issues relating to managers having left, busy schedules, and security clearance all take up valuable time and can impede successful negotiations around access. There also exists a concern for the company about what the researcher will report: could this result in liability issues, or negative exposure, and what could this mean for the company's reputation?

Considering Smith's recount of prolonged, and often unsuccessful, battles to gain entry, I was fully aware that the opportunity to be hosted for a substantial period by a busy, burgeoning organisation would not come easily. At first, I struggled to find an organisation that was open to such a partnership between industry and academia. Gill and Johnson (2002, p. 150) argue for a proactive approach to secure access, making use of "all sources of help such as friends and business contacts". Therefore, I took advantage of a personal contact to gain my initial 'in' into a company.

However, it was not just as simple as the contact 'getting me in'. Law (1994, p. 37) quips, "When they say 'It's not what you know, but whom you know' they are wrong. It's what you have, what you know, and whom you know". I believe that access to TurboUK was achieved due to a mutual need by the organisation and myself to further the understanding of education practices for this profession, my status as a PhD student from a well-regarded university, past experiences of conducting research projects, a personal connection in the company, HR processes, scheduled (and rescheduled) meetings, email chase-ups, and a good dash of perseverance. Consequently, the act of gaining entry could be understood as an ordering of heterogeneous actors: an assemblage of bits and pieces that created their own network of researcher-entering-organisation. This network of people and things needed to be aligned and mobilised to achieve ‘access’.

However, even if this network was successfully stabilised, I may have only been permitted a limited amount of time ‘inside’. Many organisations tend to be extremely busy, fast-paced and optimally resourced: hosting a researcher for a long period of time may not be top priority for managers. Researchers are now being forced to ask: what level of access to an organisation constitutes the appropriate balance between what is logistically and practically possible, with what is methodologically sound, to claim that one has completed an ‘ethnographic’ study? The next section considers a response to this question.

Negotiating length of time in the organisation

I argue that the researcher needs to attend a site for a ‘lengthy’ period of time in order to understand the value of the system they are observing, to develop a trusting rapport to inspire confidence in the participants and others in the workplace, and to grasp the work’s subtleties. Relationships that are built over time provide crucial moments where understandings of practices are revealed, thus obtaining the ‘thick description’ (Geertz, 1973) heralded as being critical for a strong ethnographic account. Furthermore, spending a longer time span in the organisation allows the researcher to observe processes and progress: the lead-up to a specific event and then the post-event reactions, and how different times of the day, and different days of the week, affect the participants.

A lengthy duration of time is also crucial for the emergent element of ethnographic design. As time passes, access to other meetings, offices, and sites may emerge as interesting areas to explore and observe. Negotiating access is not something the researcher does only once, but repeatedly through the course of one’s time *in situ* for “different groups, different people, different topics” (O’Reilly, 2005, p. 88). Therefore, I decided that I would need at least three months to “appreciate the range of norms, practices, and values, official and unofficial alike, which characterize that research setting" (Van Maanen, 2011, p. 207). Once settled, I hoped to extend my stay to six months if I was progressing satisfactorily.

The host company: Turbo

The company that agreed to host me, which I will call 'Turbo' to preserve its anonymity, is an international manufacturer of onshore and offshore wind turbines. Its headquarters, TurboHQ, are in Germany. As well as installing and developing wind turbines, Turbo provides specific solutions to projects in wind farm engineering, service and maintenance, and transport. Turbo employs over 2700[8] employees internationally. I had access to their UK subsidiary (TurboUK), based in a Scottish city. In comparing their organisational aims and the demographic of their employees with other similar organisations, TurboUK appeared to be representational of a wind energy organisation. As they agreed to proceed with the research for at least three months, I decided that this renewable energy organisation would be a reasonable choice as a research setting. At the time of the study, TurboUK employed around 120 staff. TurboUK was organised into four departments: Sales, Technical Support, Project Management and Service.[9] Many of the employees were degree-level qualified engineers working in a range of roles. This was crucial to my study, as engineers were my targeted participant audience.

In August 2012, my contact sent an email to a senior manager within TurboUK introducing me and my proposed study. After sending the initial email, my contact was no longer involved in the study in any way. On 7th September, I met three senior managers at their office to present my study and discuss their potential involvement. They were encouraging, flexible and welcoming to the idea of hosting a researcher. This could reflect the values widely expressed within this industry: to be dynamic, innovative and proactive towards professional development to meet current economic, educational and political demands. They agreed it was timely research and said that, for their own gains, they would benefit from having an 'outsider' reflect on their practices. One of the managers, Rachel,

[8] Figure correct at the time of the study
[9] There was also support departments (Human Resources, Finance and Marketing), but the employees in these departments did not have engineering qualifications, as far as I was aware. Therefore, I chose not to foreground their work activities in the data I gathered.

agreed to be my principal host, acting as a point of contact, if needed, and we agreed on my start date. Rachel also advised on the ethical and legal considerations that I needed to address. These included introducing myself and the study's purpose to the whole company, establishing informed consent procedures, and responding to legal considerations. These concerns are discussed in the following section.

Ethical considerations: Establishing researcher values, informed consent and legal requirements

Reassuring the employees that I held professional researcher values and had appropriately addressed ethical and legal considerations was an important prerequisite for conducting an ethnography. During my access meeting, I assured senior management that I intended to remain respectful of the employees' busy workloads, and to be transparent, honest and flexible when recruiting employees and working with participants. I made it clear that my task was not to unearth successes and failings of individuals but to focus on engineers' practice. I provided my hosts with a written statement of these ethical commitments (see Appendix 1) as well as a participant information sheet (see Appendix 2), and an academic poster that outlined my study. I also wrote an article to be included in their monthly UK newsletter introducing my project, and Rachel distributed a similar email, company-wide.

However, despite this focus on implicit trust of the organisation, I also needed to gain written informed consent from the individual participants who voluntarily agreed to collaborate in the research study. The consent form is a crucial formal agreement between researcher and participant that clearly and concisely states the nature of the research the participant will be involved in, what their time commitments will entail and what is expected from both parties. Most importantly, it ensures that the participant has been made aware of any ethical concerns related to the study (Punch, 1998). I compiled a participant consent form by drawing on recommendations from Murphy and Dingwall (2001) (see Appendix 3).

As the nature of an ethnographic study is emergent, the design and research focus cannot be presented as a full and complete account to the participants before the researcher commences their study (Angrosino & Mays de Perez, 2000). Therefore, the accounts that “ethnographic researchers give to potential research participants are inevitably partial without necessarily reflecting any desire to deceive” (Murphy & Dingwall, 2007, p. 2226). Furthermore, as gaining consent is “a relational and sequential process rather than a contractual agreement” (Murphy & Dingwall, 2007, p. 2226), informed consent would need to be negotiated and renegotiated over time as the relationship develops between the researcher and the host site. This point is especially pertinent to my study as it is only once the research began that I could identify who and what would be useful outside of my initial key participants.

Murphy and Dingwall (2007) question how far informed consent should extend in an ethnographic setting because, during extended periods of observation, the researcher will encounter many people who are just ‘passing through’ or in the background of the office space. It is the researcher’s responsibility to use situational judgement to “distinguish between those for whom the research is likely to be consequential and those who are tangential. Often the risk of harm is so minimal that it is not clear whose interests obtaining consent actually serves” (Murphy & Dingwall, 2007, p. 2230). Along these lines, I made it clear that I would only be collecting data from those who had given both explicit verbal and written consent. At the start of interviews, and (when appropriate) before an observation or meeting, I stressed that anonymity would be upheld. However, in constantly reminding participants about my presence as a researcher and their rights to anonymity, I may have become a nuisance and this may be counterproductive to ‘blending in’, so I had to consider how to strike the right balance.

With regards legal requirements, TurboUK, as with other similar organisations in this emerging industry, operates in a highly sensitive and competitive environment, dealing daily with confidential information, both internally and externally with clients. Therefore, the head of their legal department composed a Non-Disclosure Agreement for me to sign, ensuring that I would respect confidential information. This Agreement was counter-signed by the Managing Director and we both retained a copy.

I made it clear to senior management that any publications generated from my data gathered during my research would be intended for academic purposes only. By default, I would always use pseudonyms to respect the company and participants' anonymity. However, if they wanted to profile my work to demonstrate a positive partnership with academia, we would discuss how I presented the data. The wind industry is relatively small, and some of the descriptions of the projects may be identifiable to others in the industry, despite the use of pseudonyms, so this needed to be considered.

Caution is also required when the ethnographer explains the research at the start of the study, as, "there is often a temptation to over-claim the potential contribution of a piece of research to solving participants' current problems" (Murphy & Dingwall, 2007, p. 2227). Therefore, it is both prudent and ethical to clarify what can reasonably be expected from the research at the outset. In this instance, I made it clear that I would be happy to report back with recommendations for induction processes and suggestions for team communication improvements as well as providing them with a summary report of my research. Before I could take a critical step back to observe these processes, I needed to understand what the employees at TurboUK did every day, and why. The next section reflects on my first few weeks as I 'learnt the ropes' of TurboUK.

The first few weeks: Learning the ropes

My entry into the company was gradual. I was hesitant and nervous, not sure whether people had pieced together that this new person at the desk was the same one being introduced in the emails and newsletter. I was also concerned that there would be barriers to my acceptance. The fear of being caught up in some political game I was unaware of, putting too much pressure on people with busy schedules who were operating in a fast-paced organisation (and the very reason I wanted to study their practices), and a lack of confidence in the value of my research design (van der Waal, 2009) seemed real threats to my acceptance.

As van der Waal (2009) assured me, anxiety and tension are emotions characteristic of this period, and are due to "the lack of control one typically has over the unfolding process, the challenge of identifying unknown factors that influence the way the research may develop, the lack of local knowledge, and the sense of having to prove oneself academically" (p. 31). He recommends recording one's feelings and experiences at this stage to reflect on.

I also felt like a new employee in the first few weeks, learning a new job in the organisation. Watson (2011, p. 209) uses the nautical metaphor of "learning the ropes" to describe the actions of a "good ethnographer" who is in this position:

> What a good ethnographer does, in effect, is to write about the understandings they acquire as they learn the ropes of a particular organizational or occupational setting (or type of setting) in such a way that, in principle, any reader would be able to cope and survive on board such organizational vessels – whether they board those vessels as sailors, passengers, or officers.

Therefore, I duly recorded my reflections as I took the time 'to learn the ropes' while my recruitment drive slowly gained momentum. I used this time to meet with head of marketing to obtain an understanding of the organisation. She explained how the organisation was laid out physically (open-planned offices, flanked by private, glass-panelled meeting rooms, and occupying two floors in a seven-storey building) and hierarchically (evidenced in organisational charts and PR materials). As my understanding of the organisation increased, I found the recruitment process easier to navigate. I now turn to discuss how I recruited participants.

Recruiting participants

I made it clear in both Rachel's introductory email and the newsletter article that I was recruiting employees as participants who had an HE qualification in engineering. I asked those interested in volunteering to contact me via email. These engineers would be the key participants during the study but, as I was interested in a networked approach to knowing, I would also follow other actors (human and non-human) who were related to their network, and who would be identified as the study progressed.

I was invited to attend each department's weekly team meetings to encourage recruitment. At these meetings, I introduced myself, outlined my research project and explained the reason for my presence in the company. I briefly addressed their time commitments and reassured them of any ethical concerns. I handed out my business card and asked those who were interested to email me to arrange an initial meeting to discuss their involvement further.

I also recruited participants in an opportunistic way. Employees who had seen my article in the newsletter or had spoken to colleagues who were participants would approach me at my desk, in the kitchen, or stop me if I walked past their desk. The reasons they gave for asking to participate were because the study was interesting and relevant to them, and they wanted to share their experiences. Over the next two weeks, 13 engineers who were employed full-time at TurboUK agreed to meet with me to discuss their participation and, consequently, all agreed to participate.

Of these 13, there were two women and 11 men. Eleven were under the average company age of 35. They spanned four departments: two were from Sales, five from Technical Support, four from Project Management, and two from Service. They held diverse engineering-based undergraduate degrees: four graduated in mechanical engineering, and four in electrical. Two studied civil engineering, and one completed their degree in industrial engineering. One participant held an undergraduate degree in physics but, as she had completed a renewable-energy-based Master's programme, as had three other participants, I decided to include her. Also, one had completed an MBA but had a Higher National Diploma rather than an undergraduate degree. Two participants had completed their PhDs (see Table 1).

It is of note to the study that once these individuals had agreed to be participants, all but one, Chris, engaged in the three scheduled interviews with apparent enthusiasm and interest.[10] Therefore, I will be treating only the information gathered from the other twelve participants as the data for my study.

[10] Chris opted out shortly after the study commenced because his commitments to his projects required him to be out of the office for the majority of the time.

Table 1: Participant demographics[11]

Participant's name	Department	Undergraduate Qualification	Postgraduate qualification	Employment duration with TurboUK
Paul	Sales	Mechanical Engineering	n/a	3 years
James	Sales	Electrical Engineering	MBA	2.5 years
Walter	Project Management	Civil Engineering	Health-and-Safety-based MSc	3.5 years
Lucy	Project Management	Industrial Engineering	n/a	4.5 years
Jeremy	Project Management	Civil Engineering	n/a	3 months
George	Technical Support	Mechanical Engineering	Renewable Energy based MSc	2 months
Gary	Technical Support	Mechanical Engineering	Renewable Energy based MSc	2.5 years
Fay	Technical Support	Physics	Renewable Energy based MSc	2.5 years
Lewis	Technical Support	Electrical Engineering	PhD	1.5 years
Brendan	Technical Support	Electrical Engineering	n/a	6.5 years
Jason	Service	Mechanical Engineering	PhD	7 months
Andy	Service	Electrical Engineering	Renewable Energy based MSc	4 years
Chris	Project Management	HND	MBA	6 years

The next section examines how I worked with multiple methods to generate data.

[11] All names have been replaced with pseudonyms to respect the participants' identities.

Designing a multiple method approach

In his study of telemedicine practice, Nicolini (2009) argues that a multiple method approach to data collection is essential because a single method cannot capture the complexity and multifaceted nature of practice. Collecting a wealth of data, Denzin (1970) argues, would increase the credibility or validity of the research because it would allow for 'triangulation', presenting a somewhat 'complete' picture. However, 'triangulation', stemming from navigational terminology, has positivist connotations that suggest that there is a fixed object that can be viewed from three different sides (Silverman, 2001).

Richardson (2000) contests that a more fitting metaphor to how qualitative researchers explore the legitimacy and credibility of a study is that of 'crystallization'. The imagery of a crystal "combines symmetry and substances with an infinite variety of shapes, substances, transmutations, multidimensionalities, and angles of approach" that affords us "a deepened, complex, thoroughly partial, understanding of the topic" (Richardson, 2000, p. 934). Therefore, to ensure a 'crystallized' approach, I used multiple ethnographic tools to 'generate materials' about the engineers' practices.

However, the methodological design was only finalised after I had spent some time in the field. After three months at TurboUK, I presented my finalised methodology to the head of HR and two heads of departments. I had revised my design to now include three interviews rather than two and had added an additional visual exercise. I checked whether I was being in any way disruptive to their office space or the participants' work routines. I had received no negative reports on my presence and, in fact, HR reported less activity in their office as participants had started to see their meetings with me as a space to talk about work instead of meeting with HR. They then offered to extend my stay for another three months and I willingly accepted.

In summary, my final methodological design included daily note-taking, participant observation, three semi-structured interviews with additional visual and creative exercises, small group discussions, attending meetings both in the office and on a wind farm site, and collecting and reviewing relevant written documents. The following section discusses these methods in relation to the relevant literature, how I incorporated them into my study, and some resulting challenges and insights.

Recording observations and reflections

For a social scientist to generate a good account of practice, Latour (2005) advises us to slow down and record everything, no matter how small or seemingly inconsequential: "from now on *everything is data*" (p. 133, original emphasis). To help me do this in the workplace, I opted to use an electronic record-keeping method rather than the four separate notebooks[12] Latour (2005) recommends. I created an Excel time sheet to record my hours, location and to keep track of my participants, the dates of their interviews and who had completed which interview. I took a notepad into meetings and interviews to take notes as I felt the screen on the laptop acted as a barrier, and could make others suspicious of what I was writing 'behind' it. After the meetings and interviews, I would type up my notes on a 'daily report' template using Microsoft Word software, and that I kept filed on my laptop.

I used this daily report to note down and describe the day's interviews, meetings, and my observations. I recorded noises, reflections, my emotional responses and paraphrased conversations. I adapted the report template from Schultze's (2000, p. 17) *'Day' Template*. This included heading prompts that I used, inspired from reading Latour (2005), which showed how I was working the theory into the analysis from an early stage, for example, "objects and humans involved", "breakdowns/improvisations" and "mistakes I made" (see Appendix 4). The report afforded me an element of consistency to structure my observations and reflections when recording the day's events. Although at times this felt tedious, I had heeded Latour's (2005) advice that, "if you don't want to take notes and to write them down well, don't try to get into sociology: it's the only way there is to become slightly more objective" (p. 135) and made sure I made copious notes each day. It also meant that when I reached the analysis stage, I did not rely on

[12] Latour (2005, p. 134-135) recommends that the first notebook should act as a log of the study, including reflections, surprises, appointments, etc. The second notebook should document a chronological order of items that allow for future analysis. The third notebook serves as a place for sketches and drafts, to encourage the writer to break with automatic writing styles. The fourth notebook acts as member-checking, and should be used to note the effects of the inquiry on the actors, and how the researcher's account adds to the assembling of the social.

my memory to recall events. The daily report was crucial in reminding me of all the interactions I had followed during the six months and keeping them visible for my later analysis. Alongside the daily report, I collected and scrutinised both physical and virtual documents that included in-house case studies, timelines and schedules, planning software, organisational charts, official company publications, and email memorandum.

Participant observation

Participant observation is often seen as the gold standard of what an ethnographic study should entail (Silverman, 2001). It can be characterised by the researcher spending extended periods of time in the research setting, personally in contact with the activities and operations of the case, and seeking what is natural in the happenings. In TurboUK, observation included watching participants' daily work practices in meetings, at their desks, in communal spaces and on wind farm site visits. Meetings provided one of the most accessible situations in which to observe interactions. I routinely attended the weekly 'Monday team meetings'. However, I needed to be self-consciously opportunistic to gain access to other meetings when they arose. For example, I was often invited to meetings after conversations in the kitchen, some meetings rolled over from other meetings, post-it notes were left on my desk with a room number and time for a meeting, and invites often emerged from participants after an interview.

In these meetings, I was acting as an 'outsider'. I did not contribute to the discussions, but remained silent, taking notes. Yet Ybema, Yanow, Wels, and Kamsteeg (2009, p. 12) argue that, to increase feelings of trust, ethnographers should join in activities and the everyday flow of the organisation: to become an "insider". For example, Van Maanen (2011) writes about ethnographer empathy where the researcher 'pretends' to be like the employee. I made sure I left the office at 'home time' rather than leaving at 3pm, and I found myself empathising with the team's emotional highs and lows related to contract wins and losses. In doing so, I had to navigate the paradox of being both at once an insider and an outsider. In this messy space, familiarity and distance become over-lapping positions that I had to constantly reflect upon.

This notion of insider/outsider dichotomy presents one of several issues of the participant observation method. It constructs a binary: one that assumes that what is on the 'inside' in the organisation already exists and can be 'entered into'. Another issue arises if the researcher thinks that they, as an observer, have an omnipotent overview of the entire organisation. As meetings were held concurrently in the office, I had to choose which meeting to attend. I had to be aware that I could not follow everything at the same time. As Haraway (1988) reminds us, we can never have a 'complete' view of the world, but if, as scientists, we strive to 'know' our world, then we must accept that this can only be achieved through "partial connections" (Law, 2004, p. 68). A final issue I discuss here, although more emerge throughout later chapters, is the difficulty of observing materials that so easily disappear in the virtual and transnational worlds enacted in the office. I address this issue in the following section, where I explore the challenges in following and making visible the objects of engineers' practice.

In the pursuit of objects: Following the actors

In an ANT-inspired study, it is important for an ethnographer to study not just relationships between human actors, but also relationships with the objects of their practice. However, as Mewes and Sørenson (2017, p. 2) point out, "methodological discussions of how to do research on objects in STS are mainly conceptual and rarely engage with the practical challenges emerging when actually doing ethnography of and with object". What practical research strategy could I therefore adopt to make visible the objects of practice?

Firstly, as I had a permanent desk space, I assumed an approach highlighted by Fenwick and Edwards (2010, p. 149) to "just sit in it [a site] for a while or wander about in it, watching, listening, thinking, perhaps talking with people in the site, until something interesting emerges". Once I had identified potential actors of interest, I was then ready to start "mapping related micro-practices worthy of further examination" (Adams & Thompson, 2016, p. 35). I was taking heed of Latour's (1987) maxim "to follow the actors", to look for "mediators *making* other mediators *do* things", human or nonhuman (Latour, 2005, p. 217, original emphasis).

"Following the actors" is one of eight heuristics Adams and Thompson (2016, p. 33) suggest for "interviewing objects", where "objects may be given a voice, and thus make them available for critical analysis". To interview an object or thing, Adams and Thompson (2016, p. 17–18) explain, is to "catch insightful glimpses of it in action, as it performs and mediates the gestures and understandings of its human employer, and as it associates with others". It is then the analyst's task to attend to what is being mobilised – be it instances of knowing, power or action – in the fluid spaces that are created by the entangled associations of actors.

I also followed Latour's (2005) four suggestions in which an ANT analyst can attend to the objects of practice and thus "multiply the occasions where this momentary visibility is enhanced enough to generate good accounts" (p. 80). These include: looking for moments of innovation (through which objects are held visible for longer); creating distance to make the familiar unfamiliar; to seek accidents and breakdowns when "completely silent intermediaries become full-blown mediators" (p. 81); and to recount events from a historical perspective. Importantly, I was not to just follow the object as a single entity, but to follow the material traces it instigated as it circulated, gathered and connected with other relations. I was looking for moments of palpable energies, where tensions were rife and impossible to ignore.

However, although I persevered in looking for traces in these recommended instances, following them proved a very challenging activity to accomplish. For example, I realised that many of the objects that were emerging as interesting to follow were being talked about, used, and translated at different temporal and spatial locations that I could not access. They were part of participants' virtual worlds, which were being mobilised at their desk space through their computers, going back and forth between emails and a document. These virtual worlds were hard to penetrate without sitting next to the participant at their desk and asking multiple questions. I found that initiating these necessary conversations in an open-planned office was distracting for others and unsettling for the participant.

Due to these challenges, as well as my predilection to resort to my original training as a psychologist and focusing on the individual, it is fair to say that I found it challenging not to conceive humans and non-humans as separate and already-defined, rather than relationally entangled within many things, a position counter to the ontological basis of ANT. I was very aware that conducting observations and following objects could only lead my exploration of engineers' knowings-in-practice so far.

Following Law's (2004, p. 2) advice that we "need to teach ourselves to know some of the realities of the world using methods unusual or unknown in social science", I decided to be more creative in how I explored the materiality of the engineers' knowing. Latour (2005, p. 79, original emphasis) suggests that, "specific tricks have to be invented to *make them* [objects] *talk*, that is, to offer descriptions of themselves, to produce *scripts* of what they are making others – humans or non-humans – do". Therefore, as well as systematically observing the engineers' everyday activities, I also experimented with the structure of the traditional research interview. The next section outlines how I adapted the ethnographic interview technique to encourage the engineers to talk about, and make visible, the objects of their practice.

Ethnographic interviewing

Ethnographic interviewing occurs in projects "in which researchers have established respectful, on-going relationships with their interviewees, including enough rapport for there to be a genuine exchange of views and enough time and openness in the interviews for the interviewees to explore purposefully with the researcher the meanings they place on events in their worlds" (Heyl, 2001, p. 369). Therefore, ethnographic interviewing elicits an understanding about what the participants know in the way that they know it. For an ANT study, it is important to let the actors guide the inquiry as only they "know what they do … and how and why they do it" (Latour, 1999a, p. 19).

An ethnographic interview focuses on allowing time for a trusting relationship to develop between interviewer and interviewee. My strategy was to engender this trust by inviting each participant to three informal, semi-structured ethnographic interviews stretched over my time at TurboUK. By the third interview, I hoped they would be much more comfortable with my presence after having seen and chatted to me over six months. If another employee in the organisation appeared to be crucial to a participant's practice, I subsequently invited that person to consent to be interviewed one-to-one.

The following sections discuss how I conducted these three interviews alongside three visual and creative tasks. These 'specific tricks' would hopefully invite the posthuman mode of inquiry of 'interviewing objects', which was foregrounded by Adams and Thompson (2016). The next section explores how I used a relational map exercise in the first interview to start untangling and bringing forth, or 'interviewing', objects and their relations in the engineers' everyday work.

First interview: Introduction and relational map exercise

Once a potential participant had registered interest in my study, I invited them to schedule a meeting room for us to conduct the first interview. Participants tended to book the meeting room for one hour, determining the maximum length of the interviews. At the beginning of the interview I explained the participant's expected involvement in the project and verbally reviewed the ethical considerations. We both signed two copies of the consent form, each retaining a copy (see Appendix 3). With their permission, I audio-recorded the interview.

The intention of the first interview was to understand the engineer's HE experience and their choices involved in their educational journey, their understanding of what it meant to do engineering both before, during and after their course, and how their perspective of engineering had altered since working in a renewable energy role. I was also interested in what role they played in the organisation and the relationships they were entangled in (see Appendix 5 for interview questions).

Originally, I had not intended to introduce a visual exercise at this stage. However, on my first day in the office, I was handed the official organisation chart to help me understand 'who was who' in the organisation. This gave me the idea to ask my participants to create a similar relational diagram, based on the idea of a 'mindmap' (popularised by Buzan & Buzan, 2006). Bagnoli (2009) used this mind map technique in her qualitative research with children, calling it a 'relational map'. Her intent was to capitalise on the traditional interview technique to provide additional ways to "open up participants' interpretations of questions, and allow a creative way of interviewing that is responsive to participants' own meanings and associations" (Bagnoli, 2009, p. 547).

However, unlike Bagnoli (2009), who asked her participants to draw a spider diagram to illustrate the relationships they had with important *people,* I was interested in eliciting understandings of how the engineers ordered themselves in relation to other people *and objects* that they encountered every day to get their work done. This was similar to the framework mapped out by Williams and Figueiredo (2014) (see p. 56). Many of the engineers were familiar with mind-map exercises from their studying days. After discussing the questions that I posed to them in the first interview, I then handed the participants a blank, white piece of A3 paper and a pen. I asked them to put their name in the middle and start to draw a diagram noting all the people, objects, things, spaces, software, and hardware that they used to proficiently accomplish their everyday job. I wanted to shift the focus from the prescribed order reflected in the human-centred, hierarchical organisational chart to one that appreciated the symmetry of human and non-human actors.

Overall, the relational map task was a success. The participants began to grasp that I was interested in their relationship with objects in their work practices and not just their relationships with colleagues or clients. It was interesting to note what they wrote down first on the map as this was often accompanied by the statement, "I couldn't get my work done without …", signifying the object's importance. The act of drawing the map allowed the participant time to think about their relationships with objects, rather than just trying to recall them verbally in a traditional interview. They often wrote down things that we had not even discussed in the previous part of the interview.

Participants completed the task with varying degrees of thoroughness. They spent from five minutes to half an hour drawing and talking about their map. Some relished the task and set about drawing detailed maps, explaining the connections, directions and reasons between each entry, or node. As can be seen in Figure 3, Paul sketched what can be understood from an ANT perspective as an assemblage of social relations beginning to entangle with particular processes and technologies, which together compelled his everyday work.

Others, however, seemed to struggle to recount the smaller details of their practice (Figure 4).

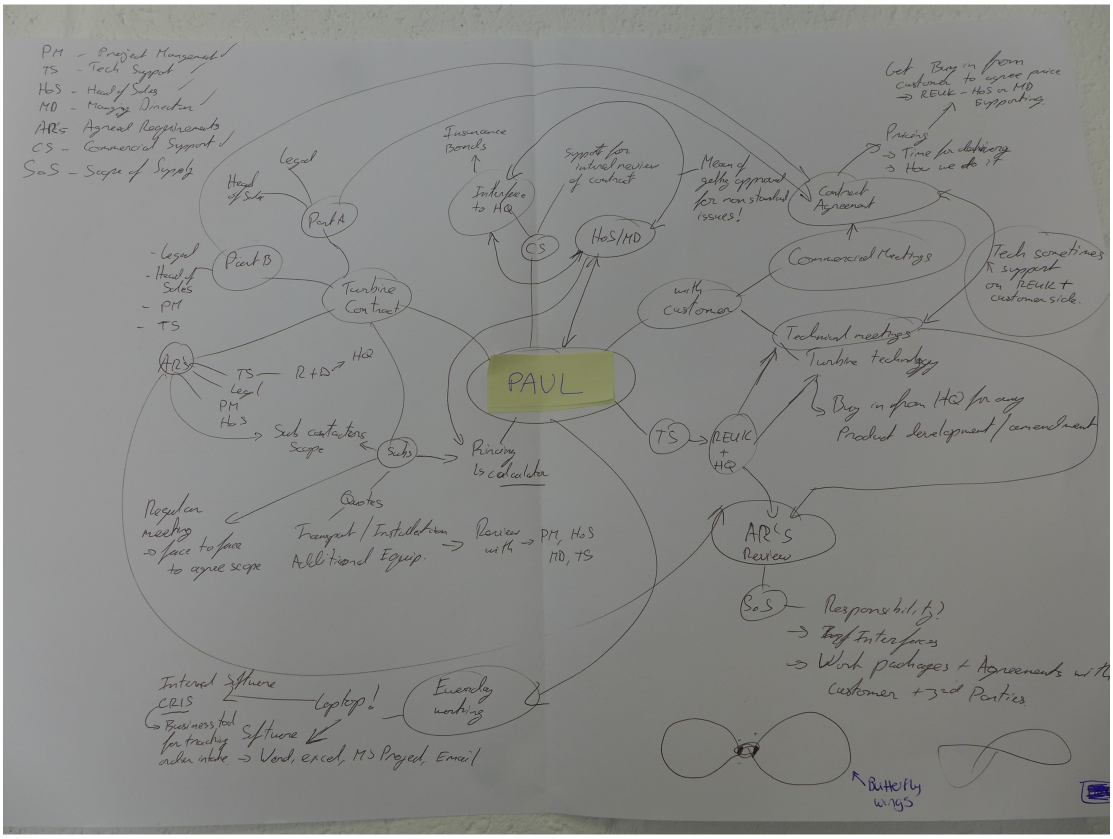


Figure 3: Paul's relational map

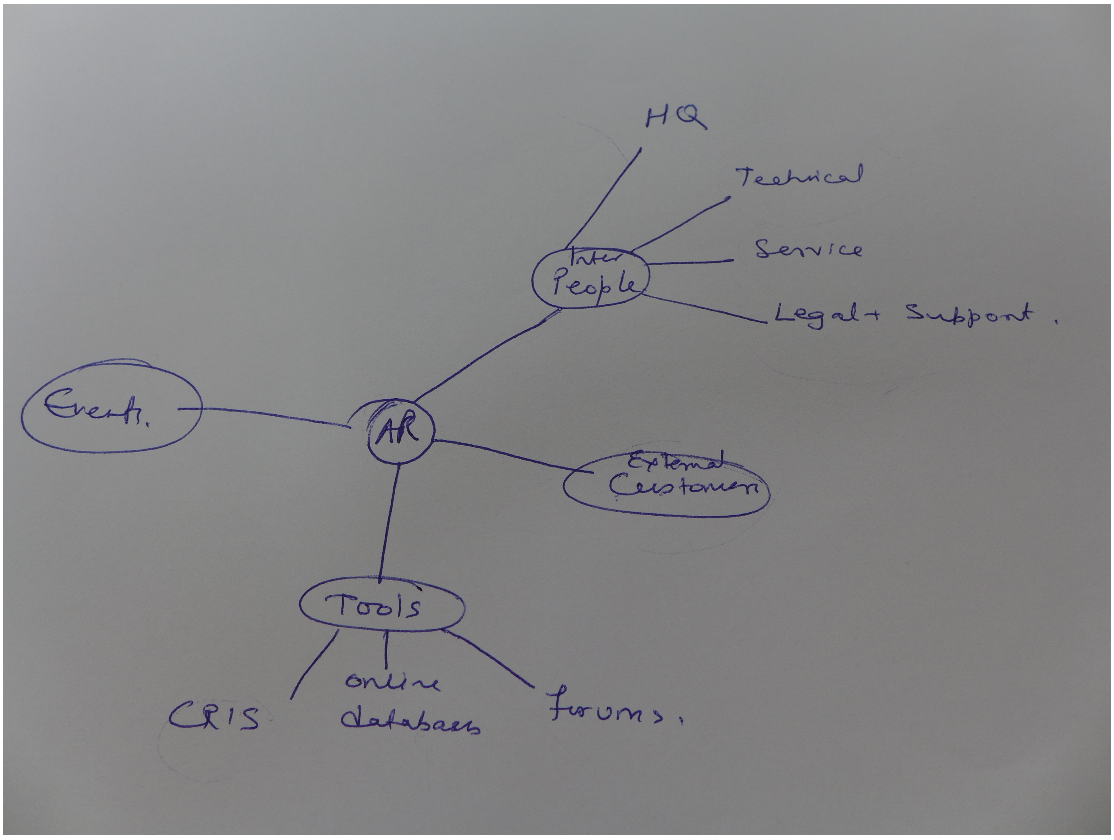


Figure 4: James' relational map

At the end of this first interview, I explained the structure of the next two interviews, the *Interview to the Double* and the photo elicitation task, to give the participants time to reflect on what they might say or what objects they might photograph. I was hoping these methodological tools would help make visible the mundane, routine and taken-for-granted aspects of the engineers' daily work practice. The next section explores how I worked with a method called 'Interview to the Double'.

Second interview: 'Interview to the Double'

It is challenging to ask participants to recall the micro-details of their practice because they often remain hidden due their taken-for-granted nature, or, as Suchman, Blomberg, Orr, and Trigg (1999, p. 398) contend, "they were quite literally unremarkable". In designing the second semi-structured interview, I looked to Nicolini's (2009) advice to develop new and innovative methods to capitalise on what he calls the critical power of the practice lens. His use of 'Interview to the Double' (ITTD) to examine everyday practice in organisational settings is one such method. This technique asks the participants to imagine that the next day a ‘double’ will come to work in their place. To avoid betraying the switch, the double must act precisely like the participant. Therefore, the participant needs to provide the double with detailed instructions on how they go about their day. The instructions are delivered directly to the interview, as ‘you’ statements: “You will arrive around 8:05 and immediately go to check the email tasks for the day”. This allows the researcher to begin to understand what the participants actually do in their everyday practice, making visible the moral and discursive elements of their working environment rather than what is prescribed in their official job descriptions.

I decided to incorporate the ITTD into the second interview, at the beginning, to encourage the participants to recall their everyday work. This had varying degrees of success. The participants often began their account in detail about how they booted up their laptop, wandered to the kitchen for a coffee and updated their to-do lists. However, when they came to describe the afternoon, they often said, “and then you just go to a few meetings and answer emails”. Many had difficulty keeping to their recall of the micro-details.

The rest of the interview was spent elaborating on issues raised in this task, as well as discussing in more detail how they used technologies in their everyday work. I normally combined this interview with a request to work-shadow the participant at their desk. However, this was often too disruptive in the open-planned office. To circumnavigate this issue, some of the participants agreed to book a meeting room for two hours, taking along the work they were engaged with that day and, as they worked their way through it, they explained to me what, how, and why they were doing their task. This then allowed me to ask questions about the tools, processes, documents and policies they were engaged with. Naturally this created an artificial environment, as they were away from their desk space, colleagues and phones. However, all the participants observed that they often booked meeting rooms to have some ‘quiet time’ to get on with their work, so a meeting room was in fact a legitimate workspace for them.

After completing all the second interviews, I had gathered vast amounts of notes and audio-recordings about the engineers’ everyday work. To provide an entry into my analysis, I needed to start limiting my networks, and consciously make absent other actor-networks that had come to my attention. It was at about this time that I began to identify several activities that I thought were significant to follow in the organisation and which would hopefully reveal engineers' particular knowings-in-practice and learning strategies. These activities mobilised actors that were creating palpable energy, taking on multiple roles, creating barriers and promulgating tensions, and/or ones that I, as the researcher, "keeps bumping into" (Adams & Thompson, 2016, p. 36). I consciously decided to gather as much data on these activities, and the actor-networks that were circulating in their performance, as was ethically, logistically and temporally possible in my time left. Therefore, for my third interview, I looked to a graphic elicitation tool, known as 'photo elicitation', to further develop an understanding of these specific activities.

Third interview: Photo elicitation task

Collier Jr (1957) developed photo elicitation as a method in answer to his question "How can you apply photographic imagery to direct research?" (p. 843). Simply, this method invites the addition of photographs into a research interview. This visual media can "jolt subjects into a new awareness of their social existence"; an awareness that a purely verbal interview may fail to achieve (Harper, 2002, p. 21). Harper remarks that, because non-sociologists often struggle to find meaning in sociological questions, photo elicitation can bridge the divide between researcher and the participant as the image can be understood, at certain levels, by both parties. Pink (2007, p. 82) writes about this as the "visual images are made meaningful through the subjective gaze of the viewer". She criticises the idea that photography is used to 'obtain' data but that it is in fact a meaning-making exercise. The collaborative aspect allows the researcher and the respondent to negotiate together the interpretation of the photo. This collaboration also relieves the pressure on the respondent from being the sole subject of the interview process.

However, as Fenwick and Landri (2012) query, whose meanings constitute what is claimed to be materiality? To address this, in their sociomaterial-inspired study of audit work, Mathisen and Nerland (2012) decided to ask their participants to highlight what they thought were the 'materials' of their practices. Following their advice, I asked the participants to also take photos of the objects and 'things' in their everyday work for our final interview. Each engineer was familiar with taking photos of land, turbines and components on-site with their camera phone. Therefore, photography was a medium that I assumed they all felt at ease with.

When scheduling their final interview, I emailed the participant with a meeting request and the following prompt (Table 2):

Table 2: Participant photograph prompt

If you can take between 3 and 5 photos (on your blackberry or camera) of any object, space, representation of an object, or 'thing' (in the widest meaning of the word!) that either helps you get your work done or inhibits how you get your work done, that'd be great! I have taken some photos we can also discuss.

I also explicitly asked them not to take photographs of people, both for ethical reasons and to keep materials the focus of the interview.

At the interview, the participants brought their photos on their camera phones or they had previously emailed them to me as JPG attachments. Their photographs included the inside of the office lift, The National Grid codebook, mobile phones, and coffee cups (see Figure 5, Figure 6, Figure 7, and Figure 8).[13] Looking at each photo in turn, I asked the participants to reflect on how working with the objects in the photos either helped or hindered their everyday activities.

[13] Most participants took photographs of their laptops, or desktops. Other photographs included pens and pencils, logos of software systems, desktop phones and meeting room.

Figure 5: The inside of the office lift

Figure 6: An empty coffee cup

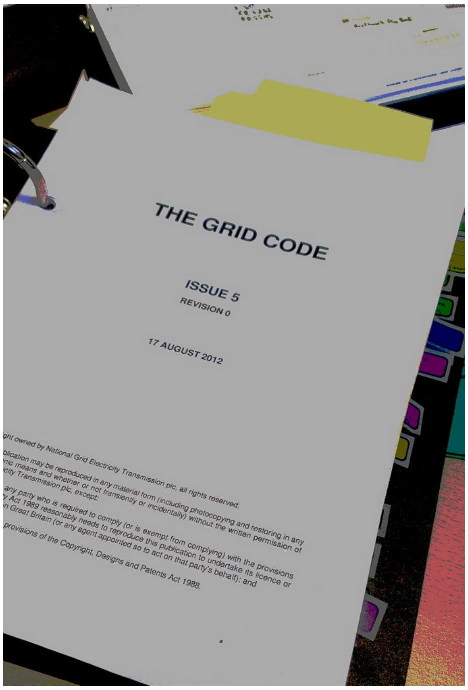


Figure 7: A standardised code book for electrical grid connections

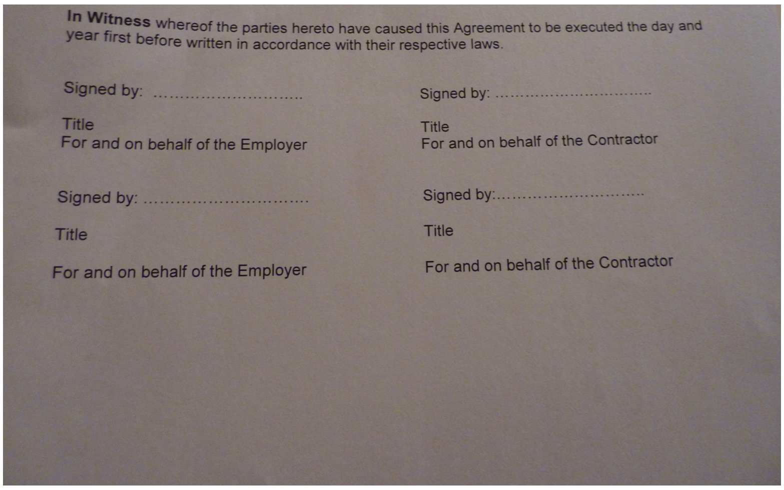
Figure 8: A mobile phone

I repeated this process with photos that I had taken during my study: compiled contracts, the signature page from a contract, the 'Stage Gate Process' cover page, a meeting room, a bell, and a door pass (see Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, and Figure 14).[14] I selected these materials because they had presented themselves as being key actors, or even as obligatory

[14] I also showed a photograph of a brochure detailing a new turbine but this is not shown for confidentiality purposes.

passage points, in ordering work. Each participant would visually recognise the objects in the photos as being part of their office routine. However, I had noticed that they either negotiated with these materials in very different ways in order to get their work done, or they had rendered these objects invisible due to their 'taken-for-grantedness' and thus did not discuss them during the purely verbal interviews. Interestingly, the participants had not taken photographs of any of these objects, except Walter, who took a photograph of a meeting room.

Figure 9: Compiled contracts



In Witness whereof the parties hereto have caused this Agreement to be executed the day and year first before written in accordance with their respective laws.

Signed by: ....

Title
For and on behalf of the Employer

Signed by: ....

Title
For and on behalf of the Contractor

Signed by: ....

Title

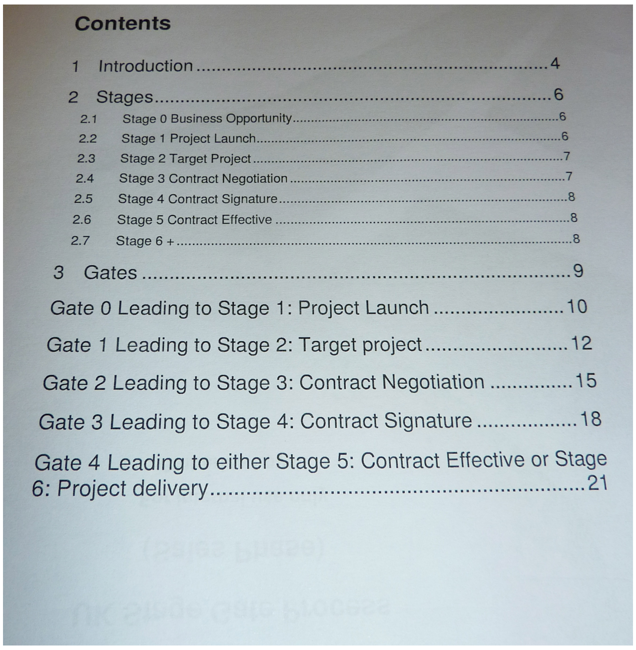
For and on behalf of the Employer

Signed by:............................

Title

For and on behalf of the Contractor

Figure 10: Page from a contract arranged for the signature of two people



Contents

Figure 11: The ‘Stage Gate Process’ cover page (an internally developed process)

Figure 12: A meeting room

Figure 13: Bell nailed to office wall

Figure 14: Door entry pass buzzing the door security system

Multiple methods, intermediaries and mediations

In line with Whatmore's (2003) assertion that data are materially generated and "act as intermediaries or 'third' parties between researchers and researched" (p. 87), it is important to acknowledge the material effects of each of the multiple methods I employed. The photos, for example, acted as an intermediary in the third interview. They performed as a frozen snapshot of time and mediated our discussions, the participants' insights and the questions I subsequently asked. These mediations jostled with the mediations from the other intermediaries I had introduced in the ITTD and the relational map interviews. However, as discussed in the following section, the strategy for my analysis does not refer to the photos or relational maps directly, other than to act as illustration. Instead, these jostling mediations contradicted, amplified and raised questions about my observations and other interviews, with the aim being not to “fight until a single pattern holds, but to add on ever more layers, and enrich the repertoire” (Mol, 2010, p. 257).

Reaching saturation point

Around the end of February 2013, I noticed repetition in my daily report; I felt I was not observing anything new in the meetings and I had completed all the participants’ interviews. I mentioned to Rachel that I thought I should start wrapping up and preparing to exit. She supported this decision. After six months of attending the office, I concluded that I was ‘saturated’ with data. My last day was 6th March, 2013. Rachel sent out a thank-you letter on my behalf (see Appendix 6) and I bought boxes of chocolates as gifts to leave in the kitchen with a hand-written thank-you note.

Considering reflexivity, positionality and representation

Before I entered the field, it was important to acknowledge that, as a researcher, the materials I was bringing forth were being framed in certain ways through different layers of mediations, and I needed to be reflexive about this process. Some researchers may hold on to a fragile fiction that, as an observer, they are not intervening. However, despite possible attempts to remain ‘non-intervening’ (Adler & Adler, 1994), a researcher will always influence the setting she is observing. She is a positioned artefact in the very situation she intends to study (Angrosino & Mays de Perez, 2000). That is, researchers enter the field imbued with their own subjective and personal attributes and assumptions. Schultze (2000), for example, found that her body language and her analytical standpoint, although unconsciously displayed on her part, were picked up on by her participants, and influenced the way they interacted with her as a researcher. At TurboUK, I was positioned as a political body coming from an academic institution to ‘conduct research’, perhaps viewed to be making judgements and evaluations of the employees’ professional practice. Thus, what my participants chose to reveal to me in interviews was mediated by this awareness; they were performing to a specific political audience.

I was a different body and voice moving in the office space and adding to the work dynamics. My performance as an ‘outsider’ researcher had to be negotiated with the performance of the workplace. For example, one Monday I joined a weekly sales meeting and, as we all filed into the seats around the boardroom table, not one seat was left empty. Just after the meeting started, the managing director came in and looked around for a seat. I was suddenly very aware of my interloping. An awkward thirty seconds passed as I debated what to do (I stayed seated)!

Angrosino and Mays de Perez (2000) note that it is important to recognise that an ethnographer will give cues to their audience. Adhering to the organisation’s dress code and maintaining a conscious effort to learn the routines, the cultural references and organisation’s acronyms can be the first steps taken by the ethnographer to increase trust and acceptance into the field. However, there were some cues that were beyond my control to modify, and these added further layers of mediation to my observations.

As a white, English woman in her thirties, entering a profession traditionally dominated by men, I will have left the field having evoked different stories than if I were an older, Scottish man. A telling instance occurred when I was on a windfarm site one day with a participant (Walter). Just before attending a site meeting, I asked where I could find the ladies’ toilet. I was shown a temporary unit of toilets next to the office cabin. The man who led me there quipped that he didn’t know what condition it was in, as there were hardly ever any women on site to use it. As I closed the door behind me, I heard an ominous grating sound. I realised the door, not used to being shut through lack of use, had jammed against the steel floor. No amount of pushing or shoving would move it. I had left my phone in the office so I could not call Walter. There was nothing for it except to start shouting, first feebly and then rather loudly. Much to my embarrassment, Walter, accompanied by two of the civil contractors, thought I was taking a long time so came to see if I was okay. With more pulling and heaving, the door became free and I slunk back to the meeting, feeling very much a nuisance. I think the others felt as awkward as I did: rescuing women from the ladies' toilets was not normal practice for them. The effect of my gender and the materials it mobilised (ladies' toilets, stuck doors) raises interesting questions about engineering practice and gender and, as inviting as these are to address, my research questions do not include this phenomenon in their scope.

Finally, it was important to consider the limits of the network to be studied, as "one could trace forever outward" (Strathern, 1996, p. 529). This requires the researcher to reflect on which networks to follow and to foreground, and which to deliberately de-emphasise or even omit from the research. Thus, I had to be aware of whose voices I chose to attune to (Heyl, 2001) and which events I decided to attend because these decisions imbue the researcher with a certain amount of power to represent. For example, it was my interpretation of an event, or what I chose as a moment to represent as an event, that bestowed its importance. If there were two meetings happening at once, I had to choose which one to observe. These choices immediately foregrounded some workers, objects and process, while back-grounding others in a process of representation that Law (2004) would term 'othered'.

This section shows how important it was to reflect on my positioning as a researcher who influenced the research setting. However, to strengthen my research, I needed to adopt strategies that would demonstrate *how* I conducted myself as a 'good' ethnographer, beyond simply acknowledging the ways in which my presence was shaping the materials gathered. These strategies are explored in the following section, where I detail how I defended my methodological strategy's worth and rigour.

Ascertaining trustworthiness: The 'controversial agency of the author'

> Ethnography is also a story of research – and in some measure, a tale about the conduct of the ethnographer as well … for research, too, is a process of ordering.
>
> Law, 1994, p. 4

When reflecting on the worth and rigour of my ethnographic methodology, I was not concerned with the constructs of reliability and validity that are normally associated with some empirical research. Instead, the notion of ‘trustworthiness’ seemed more fitting (Lincoln & Guba, 1985). Lincoln and Guba outline four constructs of ‘trustworthiness’: credibility, dependability, transferability, and confirmability. However, in accordance with ANT sensibilities, I am not interested in making grand claims to generalise or guarantee transferability, as Latour (2005, p. 136), would contend:

> To add in a messy way to a messy account of a messy world does not seem like a very grandiose activity. But we are not after grandeur.

I construe trustworthiness to imply a commitment from the researcher towards transparency, reflexivity and criticality, to ensure that accounts recorded by the researcher are ‘good accounts’. A ‘good account’, according to Latour (2005), should “*perform* the social in the precise sense that some of the participants in the action – through the controversial agency of the author – will be *assembled* in such a way that they can be *collected* together” (p. 138, original emphasis). In this study, approaches to ascertain trustworthiness and to challenge the “controversial agency of the author” included a self-reflexive approach to writing, prolonged engagement in the field with in-depth recording of observations, and seeking appropriate spaces for critical reflection and auditing from participants, colleagues and supervisors.

As Law (1994) notes above, the story of research is also an account of how the researcher positions themselves as part of the data collection. To convey this as clearly as possible, literacy ethnographer Chiseri-Strater (1996, p. 123) advises that, “the only direct way for a reader to obtain information about how positioning affects methodology is for the researcher to write about it”. Therefore, writing a self-revealing account is important in establishing the reader’s trust. In her ethnographic work, Schultze (2000) looks to Van Maanen’s (1988) ‘confessional’ and Behar’s (1996) ‘vulnerable’ accounts of ethnographic research to situate the ethnographer as self-reflexive and self-revealing when recounting their research process and experience. Schultze (2000, p. 29) states that:

> the two criteria for confessional writing are that the text must reveal personal details about the ethnographer, even if this implies presenting an unflattering image of the researcher, and

> that the autobiographical material should ideally be interlaced with the "actual" ethnographic material.

Fittingly, the researcher should adopt the use of personal pronouns to situate him or herself in the text as a fallible human being whose actions, revelations and reflections can resonate with the intended audience – "the researcher needs to bend back upon herself to make herself as well as the other an object of study … Turning in upon ourselves as researchers makes us look subjectively and reflexively at how we are positioned" (Chiseri-Strater, 1996, p. 119). These confessions would include personal details such as age, gender, race, how one dresses and comports themselves, epistemological assumptions, and theoretical standpoints. Revealing these relevant aspects of oneself invites readers to view those being describing as situated in a process that is inherently partial and relevant to time, place and social context rather than as a perfect representative of the culture or organisation under study (Haraway, 1988).

I employed reflective writing tools such as composing conference papers (Scoles, 2013; 2017a), co-authoring a book chapter (Fenwick, Doyle, Michael, & Scoles, 2015), and creating a blog[15] to explore my thought processes and to practise writing what a 'good account' may look like. Latour (2005, p. 137) maintains that if a description needs further explanation, then the description has fallen short of its purpose as a 'good account'. He recommends practising with ideas, metaphors and sketches throughout the research process so that when the time comes to sit down and start writing the final report, the author does not fall back on the automatic writing styles and clichés typically reached for by those writing about the social. This perspective situates the notion of trustworthiness *within* the writing.

I spent a total of 278 hours, over 6 months, up to four days a week, immersed in the daily life of TurboUK. Given that, these days, some ethnographic researchers are more likely to adopt the 'jet plane' approach to ethnography (Bate, 1997) – swooping in to the field with a fly-by-night manoeuvre to snatch the data – this

[15] I used Wordpress to create a personal blog about my PhD experiences and to play around with ideas about sociomateriality, ethnography and ANT: http://theofficedog.wordpress.comtheofficedog as well as contributing to professional blogs: http://propelmatters.stir.ac.uk/2017/05/17/metaphorically-speaking-word-play-in-actor-network-theory/

substantial engagement afforded me the appropriate length of time to adjust my methodological design, make extensive field notes and to attune to material traces. The reflective prompts included in my ‘daily report’ served as acts of “memoing” (Miles & Huberman, 1994, p. 74). Being reminded daily to note “little conceptual epiphanies” (Miles & Huberman, 1994, p. 74) that I observed and reflected upon during my study, I could start making associations between different sociomaterial traces.

As I discussed in the previous section, throughout my data collection and analysis process I remained reflexive about the reasons why I had chosen to follow specific materials, and make absent others. These choices may in part reflect my personal preferences, ontological and epistemological assumptions, and emerging patterns that I chose to focus on in my observations.

Regular interaction with other professionals created spaces for auditing and counsel. My supervisors acted as auditors, questioning my data and critically interrupting my immersion in the field. In the field, I consistently checked my interpretation of meetings and observations with my key host, Rachel, which also alerted me to other events I could be missing as I began to constrain my networks. Each participant received printed transcripts of their interviews along with a thank-you note and an explanation of how the data collected would be used. This member checking (Lincoln & Guba, 1985) was not an attempt to prove my findings were dependable or repeatable. After all, if my understanding of the world is one of messiness, partiality and performance, I readily expected my respondents to hold different perspectives of the raw data than me (Sandelowski, 1993). Instead, member checking provided an opportunity for the participants to inform me if I had misheard or mistyped any of their statements. Finally, I reached out for counsel from professional colleagues also engaged with sociomaterial writings and with whom I developed a close network during my PhD process.

Engaging with these specific approaches to ascertain trustworthiness, I anticipated that the value and worth of my findings could be defended, and that readers of this work could critically and visibly access my methodological and analytical journey from a sociomaterial sensibility. The next section explores my analytical journey in more detail.

Ordering and story-telling: An ANT-inspired analysis

In accordance with the material semiotics of ANT, and the emergent nature of ethnography, my analysis was an open-ended process, with the destination unknown. I 'started' the process as soon as I began my negotiations with TurboUK, recording all my movements and reflections of the inquiry itself. After amassing large amounts of data, it was necessary to engage with a form of indexing, or sorting, of the materials into a coherent form. Recording my observations and reflections in my 'daily report' provided a chronological order to my field notes. These field notes, along with the three transcribed interviews for each participant, and supplementary interviews, constituted the data to be analysed.

Although a highly time-consuming task, I transcribed the 33 audio-recorded interviews onto Microsoft Word myself, verbatim (stored in password-protected files). Rather than an administrative burden, I saw this as a crucial step of the analysis – a second opportunity to hear the participants' voices in real time. In this context, I could take my time deliberating over their comments, pausing the audio-recorder to make notes on the side of the transcripts. I then read and reread the transcripts and the daily reports, as well as the other visual materials, "going through the data again and again and then again" (Neyland, 2008, p. 21).

The next step in organising my data was particularly difficult. I found it very challenging not to default to the traditional analysis process used by many qualitative enquirers of grouping the data into 'themes' and 'categories'. As discussed on p. 46, Latour (2005) argues that the scientific enquirer will often substitute the phenomenon under critique, or analysis, with another social constituent, most likely an abstraction, to explain and thus categorise the phenomenon. Therefore, to remain true to a sociomaterial sensibility, I had to be aware of this predilection to 'fit' my data into explanatory hierarchies, and instead seek alternative ways to make sense of my material. I needed to treat my data that detailed engineers' everyday work routines at TurboUK as a 'sociology of associations', tracing connections and translations between actors by treating the social as being constituted through the particular and the local.

In line with this ANT perspective that, "knowledge practices are performative, enacting whatever it is that they are reporting" (Law, 2009, p. 240), I decided to present my analysis as descriptive textual accounts: to use ANT as a "story-telling tool" (Law, 2007, p. 2). This description of textual accounts, Latour (2005) contends, is no mean feat for the social scientist. It is in fact "the highest and rarest achievement" (p. 137), and is no less artificial than a physics experiment conducted in a laboratory. It is an attempt at a process of ordering (Law, 1994). A good textual account should describe the traces that are left behind by some active agent, and therefore should exhibit an increase in the relative proportion of mediators to intermediaries:

> If the social circulates and is visible only when it shines through the concatenations of mediators, then this is what has to be replicated, cultivated, elicited, and expressed by our textual accounts. The task is to *deploy* actors as networks – hence the hyphen in the composite word "actor-network."
>
> Latour, 2005, p. 136, original emphasis

In this sense, ANT-inspired work and description are inextricably linked: "theory is embedded and extended in empirical practice, and practice itself is necessarily theoretical" (Law, 2008, p. 141).

However, I will fall back on some contextual explanations in this story to refer to phenomena, such as 'wind energy'. Although I have started to tease this phenomenon apart in Chapter 1, the dictation of a word-limited thesis does not allow me to follow all the connections that hold stable all the networks I refer to in this study. Latour (2005, p. 147) consents to this punctuated approach, stating, "you can keep them as short-hand or to quickly fill in the parts of your picture that make no difference to you, but don't believe they explain anything". Therefore, I am aware of the immense difficulty I face in undertaking an analysis that tries to keep the social flat and unfolded, and I recognise the practical limitations that this presents. Nevertheless, I am following Latour's (2005, p. 148–149) advice for PhD candidates wondering how to produce a completed analysis that follows an ANT sensibility: "the best you will be able to do as a PhD student is *add* a text … to a given state of affairs … that will or *will not* capture the actor-network you wish to study".

So, how to present this analysed data, which has unfolded as messy, fragile, and incomplete, to add to a text that can begin to answer, or at least shed light on, my research questions? First, I had to turn my subjective experiences of events into epistemic moments and objects. In her ethnography, Schultze (2000, p. 17) argues that this "object-like reincarnation" allows the data to be considered and interpreted by others other than oneself as the researcher.

Resonating with the story-telling characteristic of ANT, Adams and Thompson (2016) suggest the use of posthuman anecdotes as one of their eight heuristics that can be appropriated to critically examine the materials of everyday and professional practices. They write that anecdotes are, "little stories—*petits récits*—woven into the fabric of ordinary conversation. In telling an anecdote, we are recounting, in lived-through detail, an incident or life happening that strikes, interests or otherwise concerns us" (p. 25, original emphasis). To ensure trustworthiness, the anecdote must be fictionally true and should be crafted referring to multiple sources. For example, I could interlace material traces recorded in my daily report notes, transcribed from interview snippets discussing the objects in the photographs and lifted from notes taken during team meetings, to (re)construct an anecdote. It is this mediation of jostling data sources that helps incorporate the non-human as well as the human actors into an anecdote, inviting the things to speak, and to be spoken about. However, it is important to remember when constructing an anecdote that traces the object that it is more than just "mentioning their existence or presence in a particular practice, but rather providing a meaningful acknowledgement of the specific work they do (or do not do)" (Adams & Thompson, 2016, p. 30).

To create these descriptive textual accounts and posthuman anecdotes, I needed to find a way to reduce my wealth of data (literally hundreds of pages) to focus on the particular material traces and associations that were useful for this study. At the same time, I needed to keep theses material traces enmeshed and entangled in the patterns of my data to remain true to the concept of a network, and not lose sight of their connections.

Although I had attended qualitative analysis software training days, I was attracted by a recommendation from a colleague to use Microsoft Word as the software programme to order, sift through and reduce my written data (Hahn, 2008). I was already familiar with Word's functions and, as my transcripts and daily reports were already filed in Word, keeping them there rather than transferring them to another piece of software would limit their translation. I was not interested in looking for the interpretations made by engineers, but for signs that pointed to an understanding of the performances involved in the organising of engineers' practice (Latour, 2005). Therefore, my analytical task was to trace these sociomaterial assemblages – the actor-networks – through the production of 'good' textual accounts, which would demonstrate my attempt at ordering (Law, 1994).

Table 3 outlines the steps I took to begin my analysis:

	Action
1.	A copy of each completed interview transcription and daily report entry was saved as a new Word document, numbering each page.
2.	Turned text into table: each separate row represented a new direction taken in the interview conversation or was an excerpt of a daily report entry.
3.	Added two blank columns to the left of the separated speech acts: the first column numerically listed the order of the speech acts for later reference; the second noted the general activity that was being performed (i.e. act of signing a contract)
4.	Used 'Track changes' and 'Insert comment' tools to make conceptual notes as I read through the data as well as reflecting on what material traces I had made absent.
5.	Used Word functions (different colours, fonts, sizes, **bold**, *italics*) to designate moments in the speech acts that foregrounded the particular material traces and associations. Noted their corresponding activity in the column to the left.
6.	Used 'Table of Authorities' (a 'References' function in Word) to select and pull out from the data, for analytical purposes, the moments that exposed the particular material traces and associations I was following.
7.	After each document was thoroughly read through using this process, I inserted a 'Table of Authorities' into the start of every document. This organised all the speech acts that foregrounded the material traces I was following in each document into a 'story' of different activities. Each selected speech act in this 'story' was referenced to a page number in the original document to help organise the data.
8.	Each participants' account for each activity, which included all the highlighted material traces and associations, was then added to the other participants' 'stories', alongside the analysed daily reports, as an attempt at ordering a 'good textual account' of how professional knowing was being performed in emerging industries.

Table 3: Analysis process

Chapter Summary

In this chapter, I have delineated the research setting and presented the research strategy, including the methodological tools I worked with to generate data. I described the challenges of negotiating access to TurboUK. I addressed ethical and legal issues, including participant consent. I outlined the recruitment process and presented the demographics of the voluntary participants. I detailed the multiple methods of data collection that I adopted to try to tease out the complexity and messiness of engineers' practices. I then discussed issues of reflexivity, positionality and representation, and how I defended the strengths of my research strategy. I concluded with an exploration of the analytical strategy I developed, drawing on descriptive textual accounts, or stories, of how knowings-in-practice were being performed in engineers' everyday work in an emerging industry.

The following three chapters are my stories of these illuminating accounts. Three on-going activities created a lot of energy and material traces during my time in the research setting and in the re-reading of the data. Foregrounding these three activities helped structure my stories: the act of obtaining a signature on a contract, the unfolding of a specific organising process, and implementing a new turbine, the Exalt. Using description and posthuman anecdotes, I work recursively with the theory and the gathered materials to analyse the work practices mobilised in these activities. By paying attention to the human and non-human associations in these activities, I foreground the tensions that professional engineers were negotiating as they worked in a volatile, high-change, emerging industry, and highlight the knowings-in-practice and learning strategies that were being evoked by these tensions.

Chapter 4: Accomplishing a signature

In this chapter, I explore the work enacted by engineers to obtain a signature on a contract that confirmed the sale of TurboUK turbines. Inspired by scholarship exploring a sociomaterial perspective of professional accountability and 'the signature' (Fenwick, Elkjaer, Brandi, Jensen, Gherardi & Landri, 2012b; Gherardi & Landri, 2014; Hopwood, 2014.), I aim to further these discussions by exploring how the work of, and around, the signature evoked particular knowings-in-practice and learning strategies. Following an ANT sensibility, I have come to understand the process of obtaining a signature as an 'accomplishment': the relational ordering, or alignment, of multiple (often unruly) human *and* non-human actors. I trace the associations between these actors to highlight how the accomplishment of a signature in TurboUK was a complex and slippery process. This entailed high-levels of conflict, negotiation, and compromise, which shone a light on the competing demands engineers were facing in their day-to-day work. In the following sections, I draw on ANT-inspired concepts to analyse the 'invisible work' (Star, 1999) that was enacted to accomplish the signature, and to articulate "both the means through which associations are established and the way in which they are kept in place" (Nicolini, 2011, p. 605).

In the first sections, I look to the analytical concepts of obligatory passage point (Callon, 1986a) to show how the alignment of distributed activities was not solely a human endeavour, despite a sales engineer acting as the gatekeeper of the process. In the second section, I draw on the notion of boundary objects (Star & Griesemer, 1989) to explore how the networks that enacted a pre-signed contract circulated and jostled in the workplace, and enrolled numerous actors that sometimes resisted being gathered. This generated particular knowings-in-practice and learning strategies, including balancing professional responsibility with commercial aims, use of embodied performances in negotiation practices, and assessing the professional boundaries in establishing trade-offs.

In the third section, I look to the analytical concepts of Latour's (1999b) factishes, and Latour's (2004) matters of fact and matters of concern, to show the effect of the signature itself on the process of signing a contract. I show how engineers' professional knowing was being shaped by practices enacted as political endeavours, steeped in tradition, etiquette and social fabrication. In the final section, I work with Mol's (2002) notion of multiplicity to explore how, through practices of printing, digitalisation and archiving, the signed contract was not only being perceived differently; it was being enacted differently as 'contracts multiple'.

"Without signing contracts, we don't have a job": The practices of accomplishing a signature

Every day in the TurboUK office, I would walk past a bell nailed to the wall. It was a bronze bell, nautical in style, with a hefty knotted rope dangling from the clapper, begging to be pulled. Although I never heard it ring, its presence intrigued me. Why was it there? It was more likely to be seen in a church, on a boat or in a town square than in a young, progressive company. I asked the engineers about its significance. They told me that it used to be rung once a contract had been signed, as a sign of celebration that they had 'won' a contract. Yet, in asking about the bell, I sensed that I had stirred up a feeling of resentment about this practice. When asked, many engineers told me that they considered it unfair that only the business development manager (BDM) in the sales department, who was responsible for orchestrating the signing, was invited to ring the bell. Indeed, I had observed that the accomplishment of a signature required a huge amount of on-going work. It was not a simple act attributed to one individual, but required a complex ordering of human and non-human actors to keep the activities moving forward towards completion, and continuing well after the pen had dried on the paper. The engineers seemed to resent a practice that put one person in the spotlight and diminished their collective effort.

This bell-ringing practice raised many questions for me about the work to accomplish a signature at TurboUK: How did the need for a signature shape and order the engineers' everyday work? Did it produce or reproduce helpful and unhelpful practices? Who/what was accountable for signing? What work was foregrounded and what work was marginalised during signing? What effects were evoked in the different material enactments of the signature? Most importantly, I wanted to explore what these questions implied for the engineers' knowing. This chapter takes the accomplishment of a signature on a TurboUK sales contract as a material entry point to explore these questions.

Firstly, I begin by further explaining why I was drawn to investigate the practices that emerged during the process of accomplishing a signature. To do so, I look to Hager et al.'s (2012) five principles of practice theory, described in Chapter 2, as an organising device. I do so partly to experiment with their understanding of practice theory in relation to framing the work of the signature as a collection of knowledgeable, sociomaterial practices, and partly to illustrate how practice theory could be a useful framework for teaching future engineers about engineering *practice*, which I discuss later in the thesis. I also look to scholarship on the history of the signature by Fraenkel (2006), and a special issue of *Professions and Professionalism* by researchers who were interested in tracing the material enactments of a signature to explore professional accountabilities at work (e.g., Gherardi & Landri, 2014; Hopwood, 2014).

It is first useful to explain why I was drawn to follow the specific activities involved in accomplishing a signature by situating them within a wider story, that of TurboUK's operational aims and doings as a competitive organisation in the volatile wind energy industry. Many of the employees I talked to acknowledged that TurboUK was a sales-driven organisation. It had quickly become apparent to me that obtaining a client's signature on a contract to confirm purchase of TurboUK turbines was the driving force of the engineers' daily work. This was not just a priority for the engineers in a sales role at TurboUK, but also for engineers employed as electrical, mechanical and civil engineers in technical support, project management and product servicing capacities. The engineers viewed the act of obtaining the signature as the end goal, but the vehicle to achieving this was the arrangement and ordering of the contract. The work generated around the activities of arranging the contract for signature was highly prominent throughout my observations: it was mentioned in nearly every meeting I attended, and was consistently referred to in all the interviews.

Obtaining a signature was a lengthy process involving considerable work, which began when a potential client selected TurboUK as their preferred supplier (subject to contract)[16] to provide the turbines for their wind farm site. At this point, a ‘project team’[17] was created to manage the arrangement of the contract. They worked together, with the client, to decide what details would be included in the contract. If the potential client accepted TurboUK’s offer, the contract they had negotiated together would be printed onto paper, ready to be signed by both the client and TurboUK. Once the contract had been signed, in the engineers’ words, they had ‘won the contract’. It was a pinnacle moment for them and represented many important implications. For example, as I will discuss later in this chapter, I observed how the moment of signing acted as a symbol of a competitive process that was ‘won’; a key performance indicator achieved; a pay-cheque to cash; the go-ahead for the Project Management department to begin installing the turbines; and a legally binding document that allocated responsibility and accountability to its signatories.

Yet, because the work of accomplishing the signature was so entangled and distributed within the engineers’ everyday activities, the work before and after the moment of signing was often taken-for-granted or unacknowledged. Interestingly, not one participant took a photo of the signature or the contract in the photo-elicitation task. It was not until I presented James with my photo of the contract signature page in the third interview that he exclaimed what an obvious over-sight he had made in not considering it a crucial object which helped their daily work. James remarked: “I guess without signing contracts we don’t have a job really! So, yeah, they’re absolutely essential!”

In observing the mundane, often taken-for-granted activities involved in accomplishing the signature, I could study how engineers’ practices were unfolding *in situ* as situated, collective actions and experiences. This has direct implications for understanding processes of knowing as ‘knowing-in-practice’. The concept of knowing-in-practice underpins Hager et al.’s (2012) first

[16] In this sense, a ‘preferred supplier’ was the supplier of turbines who were offering the turbines with the most suitable technical specifications for the wind farm project in question, and, ultimately, the ones who were the most competitively priced. ‘Subject to contract’ refers to the condition that both sides agreed to the clauses inscribed in the prepared contract.

[17] This ‘project team’ comprised a project manager (referred to as a ‘PM’, from the Project Management department), a project engineer, and an electrical engineer (from the Technical Support and Service departments) and a business development manager (known as a ‘BDM’, from the Sales department).

characteristic for theorising practice. This principle is important, as I am concerned with illustrating and analysing the engineers' knowings-in-practice as they resolve everyday work challenges in highly volatile and innovative industries.

Participants often discussed the process of signing contracts by talking about a singular, unitary object – the 'signature' (for example, Rachel talked about "supporting *the signature*"). The process itself had become a reified thing, a metonymic device. I felt I would turn a corner one day and bump straight into the signature; a physical object, revered and housed in a glass cabinet. However, from a sociomaterial sensibility, I was observing the object – here, the signature – perform as an assemblage of discourses, activities, materials, legal requirements, and social obligations, which were mobilised in the accomplishment of a signature, and indeed the act of signing itself. This understanding of the signature aligns with Hager et al.'s (2012) second principle: it was a sociomaterial phenomenon, constituted of human and non-human actors distributed through time and space.

In navigating the signing process, I did not observe the engineers referring to a textbook or a formalised set of guidelines to inform their work. The knowings involved in the act of signing did not seem to be contained purely in cognitive processes or in static textbooks outlining contract law. Instead, knowing was embodied (in bodies and in non-human objects) and travelled through relational networks involving complex arrangements of human and non-human actors, such as clients, spreadsheets, scanning software, couriers, and contract guidelines. This supports Hager et al.'s (2012) third principle of theorising practice: practices are embodied and relational.

Furthermore, the process of obtaining a signature at TurboUK did not stand alone in time and space but was enmeshed in other practices and traditions of contracts and signatures. In line with Hager et al.'s (2012, p. 4) fourth characteristic for theorising practice, these activities "exist and evolve in historical and social contexts". The practice of engaging in contracts reaches back to the philosophical debates around Social Contracts in the mid-17th century Enlightenment era (c.f. Hobbes, Locke, Kant, and Rousseau). The contract normally requires a signature

– a person's written name that represents a trusted authoritative validation to uphold the statement of promise contained on the document.

In her account of the signature's history, Fraenkel (2006) highlights that the traditional definition of a signature has developed over the sixth and sixteenth centuries, in which royal powers tried to gradually unify the signing acts in royal and papal chancellery, notary offices and local jurisdictions. The physical manifestation of a signature has changed over time. In 1554, it became forbidden to use seals or symbols as a signature act. Instead, a full patronymic name was required (first and surname) to validate deeds and documents. This has become the 'standard' sign of identity and of validation, although it is being challenged with the introduction of technology and e-signatures. Although the manifestation of the signature has many forms, its meaning is inextricably linked to operations of power, as in who has, and who does not have, the authority to sign. Therefore, signing is linked to a regime of practice that has implications for how professionals' work, practice and learning are governed (Hager et al., 2012).

For those working in TurboUK, the signature remained as a hand-written depiction of the name of the person deemed accountable to authenticate and commit the organisation to the terms and conditions presented in a written contract. Here, a contract was understood as a legal agreement entered voluntarily by two parties or more, which instigated a mutual obligation between the parties. Paul, an engineer in a BDM role, explained to me that the contract was based on the *FIDIC Conditions of Contract for Plant and Design-Build* (International Federation of Consulting Engineers, 1999), an internationally recognised and standardised contract template used by employers and contractors on construction projects. However, no two TurboUK contracts were written-up in the same way. For example, payment terms, rights of contract extension, warranties and guarantees all differed depending on the client, and the unique qualities of each site necessitated different environmental requirements, such as certain felling methods of trees in accordance with SEPA[18] guidelines.

[18] Scottish Environmental Protection Agency, an environmental regulator.

The practices enacted to accomplish the signature were therefore hard to predict in advance. They were emergent, predicating Hager et al.'s (2012) fifth principle for theorising practice. That is, although processes were in place to move forward the engineers' work, for example, the Stage Gate Process (see Chapter 5), the complexity of accomplishing a contract in a high-demand, volatile industry restricted how much certainty could be specified in advance. Constantly developing new technologies, on-going delays to manufacturing turbine parts, rapidly shifting renewable energy and environmental regulations, and sensitive relationships with the public, all played into the emergent and unpredictable nature of securing a signature. Hence, there was a palpable urgency for the engineers to obtain the signature as soon as possible, and provide a moment of stabilisation, even closure, to move their work forward, before their work was destabilised by competing forces.

In summary, mapping Hager et al.'s (2012) five principles onto the activities involved in accomplishing a signature foregrounds how the engineers' knowings-in-practice are inextricably tied to practices that are sociomaterial, relational, historically and socially embedded, and emergent. However, to analyse the knowings-in-practice and learning strategies emerging from these practices, I needed to draw on ANT-inspired concepts that could help me start to untangle the relations and their effects between the heterogeneous actors enrolled in these practices. I begin by looking to Callon's (1986a) concept of obligatory passage point to explore how a key knowing-in-practice emerged as technical coordination and alignment.

"Going around the houses": Aligning distributed activities

This section explores how, for some of the engineers at TurboUK, the planning, coordination and ordering of heterogeneous entities, which constituted a completed contract, emerged as a key knowing-in-practice. The first steps in accomplishing the signature entailed gathering and drafting the specific material constituents to be included in the contract. This activity involved mobilising and enrolling multiple actors from local networks, such as different TurboUK departments, technologies and processes, and from extended networks, including the client, competitors, government bodies, banks, environmental agencies and construction contractors.

As I have no background in law or contract work, I asked Paul to explain to me the main components of the contract. He explained that it was split into two parts. The first part, Particulars A, was only two pages, and outlined the contract details. The second part, Particular Conditions B, set out the detailed conditions of the contract and covered the amendments to the FIDIC contract template. The third part, Agreed Requirements (ARs), established the technical details of the contract, assigning responsibilities and actions. Paul commented that the ARs seemed to generate the most work:

> The third is the one that a lot of different interfaces – a lot of different parties – are involved in, and that's the one that takes a long time to reach agreement on. That could be one where we will have input from sales, legal, technical support, all the electrical team, PM, service teams, so there are a lot of different parties there and then all that input and then you probably have the equivalent on the customer side and the way its managed is it goes through … me in the middle. It comes through me as the point of contact, goes round the houses to all the guys on our side here and comes back to me. Then goes all around the houses on their side and then comes back to me … So you can imagine it as a butterfly's wings going in and out.

Paul draws on the image of butterfly wings, like that of an infinity symbol, to describe how the work was 'going around the houses'. He proceeded to sketch an infinty sign to illustrate his point that the work to order the ARs seemed to flow and circulate in a continuous loop, travelling through Paul in the centre (Figure 15):

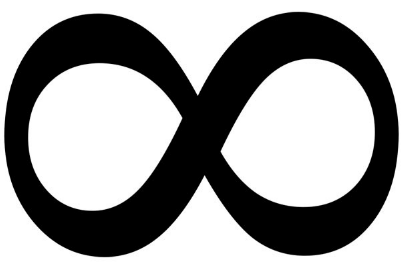


Figure 15: Infinity symbol

In ANT terms, this assemblage of relational work around the ARs could be understood as 'an obligatory passage point' (OPP) (Callon, 1986a). It had become a "central assemblage through which all relations in the network must flow at some point" (Fenwick & Edwards, 2010, p. 18). The ordering of the ARs was not a simple practice that concerned solely the author of the contract and the signatory, but was a collective and distributed activity, which enrolled bodies, documents, traditions, processes and countless other artefacts. As a gatekeeper to this information, Paul subsumed the interests of those actors, both upstream and downstream of the pre-signed contract. Acting as an OPP, Paul brought the actors together for a moment in time, inscribing the technical details into the appropriate documentation format, and then sending these back out 'around the houses' to be amended, added to or reviewed. In this position, it is tempting to see Paul as standing in the centre of the network (Law, 1987).

However, this effort at alignment was being shaped not only by human (Paul's) interest, but by many other material actors, which were often unpredictable and unruly. For example, I spent an afternoon observing Gary, an engineer in technical support, generate a model of wind analysis using specialist software. Data from this analysis would help predict how TurboUK turbines should perform on the potential client's site, and this information would form part of the ARs (Agreed Requirements). However, material actors performing in this wind analysis assemblage threatened to destabilise the results, as my following notes show:

> Gary explained to me that when the wind farm site is going through planning permission the client should initiate a measurement campaign. This consists of a meteorological mast that is erected on site for 1 – 2 years to measure several integral sectors: wind direction, average speed, speed variance, turbulence, temperature. 40% of the time Gary would say that they get good data, but the rest is very poorly representative of the site and wind speed, for example, when the recording equipment freezes in low temperatures, or when the client did not install an adequate mast. However, Gary was feeling the pressure from sales team to get the wind data processed quickly, so he had to improvise to create as detailed picture as possible. When the data is missing, he said engineers often extrapolate

> data to fit the actual turbine size. He also said he often went to site to take photos and measurements to enhance the data.

Obtaining accurate data to plot wind measurements of TurboUK turbines was being challenged by many (unruly) actors, including inappropriate meteorological masts and freezing weather conditions. Rather than abandon his task due to these obstacles, Gary would improvise to piece together the required information to pass on to Paul. He did this by enrolling other actors: extrapolated data, and taking measurements and photos on the wind farm site. Paul relied on Gary to complete this analysis, add the details to the relevant document in the ARs, which was then saved on the shared hard drive, and accessed later by Paul.

This section has shown how the planning, coordination and alignment of the material constituents of the contract was a crucial activity in accomplishing a signature. This knowing-in-practice could be termed 'technical coordination' (Trevelyan, 2007). However, analysing an assemblage that was performed to generate wind data through photos, software, met masts and visiting, showed that this coordination was not fully in control of humans, but mediated by unruly material actors.

The effort to align the elements of the pre-signed contract was only one aspect of the engineers' work. They needed to decide and agree on what was to be included in the contract speficities, for example, turbine component costs, transportation schedules, environmental assessments, payment plans, and so on. This required processes of negotiation and compromise, both with other engineers in TurboUK, and extrernally, for example, with clients and environmental bodies. The next section explores how the engineers' knowings-in-practice were being shaped by processes of negotiation and compromise, in practice.

"Finding firm ground on shifting sands": Negotiating different perspectives

In this section, I work with the concept of 'boundary object' (Star & Griesemer, 1989) to show how knowings-in-practice and learning strategies were evoked as the engineers reconciled and negotiated different perspectives, objectives and understandings of the work. These differences were being played out between the TurboUK engineers and their client, as well as between engineers *within* the organisation. Although all the engineers understood its purpose as a functioning object, I was watching the pre-signed contract work as a ‘messy object’ (Law & Singleton, 2005), being slowly stitched together through an assemblage of evaluation forms, risk assessment spreadsheets, email attachments, printed documentation, Word files stored on shared computer drives, and conversations. There were often moments of overlap, disagreement and disjunction as these heterogeneous materials were wrestled together. These knotty, opaque spaces of conflict and negotiation afforded the engineers the space and time to reconcile these different perspectives for a moment in time. As Lawrence referred to in his interview, they were “finding firm ground on shifting sands”.

To strengthen the networks holding together the pre-signed contract, and embed strategies into the contract specifications, each member of the project team contributed their technical expertise to the arrangement of the contract. This sharing of expertise as a collective effort is considered in more detail in the following chapter. Here, I look at how each engineer was arriving at these collective meetings or email exchanges with their own specific professional objective, which motivated a very different perspective about the nature of the work itself. Observing how the engineers worked though these disconnected perspectives to reconcile this messy object into a ‘completed’ object helped make visible some of the material actors at work (Latour, 2005).

During my study, I observed how the flexible interpretation of a timeline invited a process of negotiation between engineers in the sales departments and engineers in technical support and project management (PM) departments. These engineers had been tasked to arrange a contract for a particularly high-value project, Craigkenny. However, precarious government subsidy initiatives, rival firms competing with more appropriate turbine technologies, client demands, and a complex wind farm site in question were acting as unruly and hostile actors in the signing process, threatening to destabilise the work of the signature. As such, Paul, a sales engineer, was pushing to get the contract signed as quickly as possible. Yet, I noticed the engineers in the other teams were reluctant to commit to a signature until they had ensured that a review of all the technical aspects and potential risks of the project had been conducted thoroughly. I observed this tension play out in a sales meeting, as reflected in my Daily Report:

> I noticed a real tension between getting the contract to signature and the actual work hours taken to look into all the Agreed Requirements (ARs) and Project Contract Evaluations (PCE) requirements thoroughly. As the MD hammered home, the main driver is getting an offer on the table for the customer by end of January in order to meet their March deadline and bring in £XX. If any actions cannot be completed or closed before the date of the contract signature, then the action needs to be captured in the risk register. This project is under the spotlight at HQ so all eyes are on UK. Therefore they are very keen to get the signature even if they have not completed all their AR's. They just need enough done to 'get by' and once the 'signature' is obtained, it will tick the box for HQ and then they can hone the contract. They fully acknowledge that this is 'a live project that will keep moving'. To try and pin it down, Paul pushes for getting a timeline out on email to everyone to solidify dates.

Here, the timeline enrolled in the pre-signed contract assemblage was acting like a boundary object. As discussed in Chapter 2, boundary objects can act as interpretively flexible, non-human actors, which allow various actors to cooperate on a project, despite having different and oftentimes conflicting interests (Star & Griesemer, 1989). In this meeting, the timeline was referred to as though it was an actual physical object – "we are holding the timeline", which I assumed to mean 'sticking to the original plan'. Meeting requests were sent out, requesting a fortnightly recurring meeting to monitor the progress of obtaining the signature against the timeline. Spreadsheets were circulated, populated with digital representations of dates as Gantt charts (a project management tool). This materialisation of the timeline into what Latour (1987) might term an immutable object – an actor-network that was temporary stable and could evoke different practices from a distance – seemed to put pressure on the other project team members to complete their PCEs as quickly as possible. The PCE was a critical assessment tool that was completed by each project team member as part of arranging the contract. This was to ensure that the engineers in each department had considered their due diligence and that the standards of care had been addressed for each stage of the project

However, from past experiences of this rushed process, the PM and Technical Support engineers had learnt to push back on this timeline: they refused to relate to it as an immutable object. They told me that they viewed the PCE as their opportunity to address their professional responsibility to uphold health and safety regulations. These considerations took time. After all, they were the ones who had to work with the consequences of what was written in the contract, and were not happy just to 'get by'. Other actors outside of the TurboUK project team would rely on what was inscribed in the written contract to shape their work practices. For example, a heavy-goods transport company responsible for delivering the turbines to site would look to the contract for details about delivery dates. The PM engineers would have to anticipate this scheduling issue when arranging the contracts, and be careful that they had accounted for the relevant health and safety procedures, such as road closures with the council to ensure safe delivery of the turbines.

It could be argued that, in ANT terms, I was watching the PM engineers strive to keep the PCE open as matters of concern (Latour, 2004) for as long as possible. That is, they wanted to keep questioning, or keep visible, the things being gathered, or folded, into the object (the pre-signed contract). They were reluctant to close any controversies that were yet to be considered in planning for the transport of the turbines. The BDMs, on the other hand, may have been less willing to stake this time, documenting any uncompleted actions into the risk register, and smoothing over any unresolved controversies. They wanted to quickly gather all the material constituents together into an object so it could be stabilised and signed, and positioned as matters of fact (Latour, 2004).

Thus, in considering the timeline as a boundary object, I have shown that, whilst remaining a continuous source of disagreement, the engineers were still cooperating, moving forward the work of accomplishing the signature. It was within these spaces of disagreement that particular knowings-in-practice emerged. For example, the timeline was acting as a calibrating instrument, helping to balance the commercial objectives of the organisation with those practices of the more traditional engineer concerned with ensuring health and safety and risk.

Framing the pre-signed contract as a boundary object was also a useful analytical approach to explore how processes of negotiation were shaping engineers' knowing. Here, negotiation was a transactional process that entailed both parties reaching an agreement about the details of the contract through practices of compromise. Most engineers told me they had no pre-service education in learning to negotiate the terms of a contract. Yet, enacting the persuasive performance of negotiation practices seemed a crucial knowing-in-practice for the engineers' daily work, and it was not just limited to those in a sales role.

Acting as a boundary object, the pre-signed contract pulled the engineers in to meetings and discussions that demanded ways of working that were perhaps not accounted for in their traditional pre-service education. For example, I interpreted James' comment below to imply that an electrical engineers' role would not normally require them to be proficient with 'people and social skills':

> All our electrical engineers, if they are working on a project, have to face clients. So it's not what a traditional electrical engineer would do. They are supposed to actually have some people and social skills too.

The electrical engineers were valued for their technical expertise, but, enrolled as part of a collective 'project team' representing TurboUK's interests to the client, they were also expected to know how to interact with clients in a meeting. In these client meetings, saying the right or wrong thing could have costly consequences, as Paul intimated:

> [It] comes as a given with the engineering role that you're in not to say the wrong thing or to say the right thing or to word it in the correct way that fits what we want and the client hears what he wants.

An example of this came from Gary, who explained to me how he had to 'spin' the data generated from his wind analysis to keep the clients happy. I noted the following as I watched him work with the financial modelling:

> The client is interested in modelling the wind yield (how much energy a turbine can generate from wind). Yet Gary prefers to deal with wind speed rather than wind yield. This lets him take a more conservative approach on loading (the force that the turbines can take). If they predict too much yield, the TurboUK

> engineers would have to apply curtailment (shutting turbines down in a certain area to protect the other one that's down wind of it) to it to guarantee the protection of the turbine. This would create tension with client as it means they wouldn't get maximum yield so the engineers need to spin it around to make it look like they are saving the turbines from a wear and tear perspective.

It seemed quite a demanding task for electrical or mechanical engineers to know "as a given" how to "word it in the correct way". How did the engineers know, and learn, the nuances of these negotiation strategies? Paul explained how challenging it was to sense when the negotiations were unfolding in their favour:

> It's quite difficult [laughs] we need to explain it in a way that the customer goes, 'Oh that's fine,' and how it actually might happen in practice might be slightly different but it gets the end result. It's not being cloak and dagger kind of stuff but it's certain things when they're talking to us about something and if we know that they have it wrong we'll just stay quiet, 'Mm ok, we'll accept that,', but we know for ourselves that it works in our favour, and we just leave it. It's little things like that that. Often you'll get a kick under the table if you're told to keep schtum and that can easily be it at times you know. It's all part again of the negotiation and not being rash and not making decisions too quickly.

It felt to me as though the engineers had to learn to act as 'one'. They had to resolve or make invisible any disconnect that may have been generated inter-organisationally, for example, through the negotiation of the Craigkenny timeline, to present themselves as a unified front. In such instances, Koskinen and Makinen (2009, p. 34) suggest that a signed contract can become "the negotiators' interpretation of the 'world' made into a collective reality". Thus, considering the pre-signed contract (its material constituents) as a boundary object was useful to trace how engineers' knowings-in-practice were being shaped by these negotiation processes to achieve a collective reality within their project team. There were subtle strategies to be learnt by the engineers as they became part of this performance. As Paul exemplified, the practices of negotiation could be understood as collective and embodied persuasive performance. They had to learn not to make impulsive decisions, and to appreciate the value of silences. As Paul noted, it was not easy to learn the nuances of what to say, when, and in what way. Paul mentions one way that they taught each other when to remain "schtum" – with a swift kick under the table!

Another knowing-in-practice that emerged was appraising the appropriateness of trade-offs. Paul talked about this as the "second level" of negotiation:

> The second level behind [the negotiation] is understanding what we could trade in. If we could trade say, ok we'll do the delivery of the foundation rings to site. Now it's a small thing, it's a small cost, it's more work for the project management because they have to coordinate it if we do that work, but we could do something like that in return for them taking on all responsibility for the transport of other components. We'd say you do that section, we'll do this section and then it's all agreed. It's just simple trade-offs more often than not … I think it's because there's so many things that have a knock-on effect in the background. It's knowing the contract, knowing the detail, knowing how it all works.

Paul was making explicit the tacit assumption about negotiation practice that there would be a performance, in an acting sense, where give and take would be played out between the parties to satisfy each other's different objectives. In this practice, the pre-signed contract was acting as a boundary object to facilitate a shared space for this exchange. As Koskinen and Makinen (2009, p. 34) found in their study, "the intersectional nature of the negotiators' shared work is now a strongly structured boundary object (i.e., project contract) which simultaneously includes multiple views, and meets the demands of each group".

Kellogg, Orlikowski, and Yates (2006, p. 39) might refer to this space as a "trading zone", where "diverse groups can interact across boundaries by agreeing on the general procedures of exchange even while they may have different local interpretations of the objects being exchanged". It was through these negotiations in the 'trading zone' that the participants needed "to learn to communicate with and from others who have different perspectives and perhaps a different vocabulary for describing their ideas. They need to establish a common ground and a shared understanding" (Koskinen & Makinen, 2009, p. 31).

However, as the TurboUK engineers showed, generating a fully transparent shared understanding in this cooperative space was not beneficial to their negotiation outcomes. Knowing how far to push the trade-offs and when (not) to correct clients' misunderstandings was a subtle and nuanced knowing-in-practice for the engineers. They also had to assess at what point these negotiation techniques could start to undermine their professional responsibilities, where being ‘cloak and dagger’ could damage their client relationship, or even incur unwanted legal consequences.

A bell is no bell 'til you ring it: Attuning to arrangements of power

> We’ll need a signing ceremony for this one!
>
> Lawrence, BDM

In this section, I explore the knowings-in-practice and learning strategies that emerged during the moment of signing the contract. I draw on Latour’s (1999b) notion of ‘factishes’ to explore the material arrangements of power and authority (*who/what* signs) and the social fabrications associated with the act of signing (the *how/why* of signing). I specifically explore how signature ‘rules’, symbolic traditions and practices of etiquette are enacted. To do so, I draw on practices that help illustrate this: the intricate customs of penning the signature, and the performance of bell-ringing. Entwined in these practices, I highlight instances of engineers’ knowing that are concerned with attuning to complexities of power relations. Firstly, I examine how certain networks created positions of authority that invited the signing of the contract.

I was attending one of the weekly Monday Sales meetings when someone asked the whereabouts of Lawrence, one of the BDMs. I noted in my daily report the following discussion:

> James joked that Lawrence is ‘with the contract’ and ‘I hope he doesn’t leave his bag on the train!’ There was some discussion about how the actual contract got to the client: ‘Is he hand-carrying the contract?’ ‘No, it was sent down and he is going by train to the office to sign it.’ … Paul tells me later of a time they ‘got one man in a van called Jim to drive from York to Milan to pick it [contract] up and to bring it back because there was no other physical way we could do it, so it cost us a £1000 for this courier to bring five sheets of paper back to Manchester.’

Spending a thousand pounds to physically courier five sheets of paper across the continent and back again seemed a starkly impractical activity for engineers conscious of efficient processes and negotiating cost-saving strategies. This anecdote serves to highlight how the act of signing a contract was highly emergent, profoundly material, and energy intensive. Most importantly, it shows how important the engineers considered the physical act of signing of the contract was to their *modus operandi,* and what the act of signing implied for their everyday work.

I now draw on recent work by Gherardi and Landri (2014), who investigated how the act of signing could be considered as a material apparatus of professionalism. They looked to Latour's (2002) study of the Conseil d' État, and his notion of 'factishes' (1999b) to position the act of obtaining the signature as a performance of identity, validation and accountability. A 'factish' is a blend of a 'fact' and a 'fetish'. That is, the act of obtaining a signature can be understood as a both a 'matter of fact', in that it produces stable traces in professional practice that position professionals as credible and autonomous actors, as well as a 'social fabrication', which is tied up with highly entrenched values and histories around the traditions of signing. Gherardi and Landri (2014) argue that the interconnections between this mesh of matter of fact and social fabrication can be viewed as sociomaterial arrangements of power, symbolic traditions, and practices of etiquette.

Before the contract could be signed, it needed to be printed onto paper. Interestingly, I had never seen a completed paper contract up until this point. I had just experienced it as a messy object: a collection of timelines, virtual and paper documents, and discussions. Matt,[19] a commercial coordinator in the legal department, physically arranged the paper contracts into arch-lever files (see Figure 16). I joined Matt for an afternoon to talk through the contract signing process as he assembled the contracts in front of me. He had to print out three or four copies of each relevant document, creating multiple copies of the printed contract. Next, the contracts needed to be signed by the respective clients and relative authorities in TurboUK.

[19] Matt, a pseudonym, emerged as an important non-engineer in the accomplishment of the signature, and I gained his consent to be interviewed and work-shadowed.

Figure 16: Matt compiling the contracts

The process of preparing the physical contract to be signed seemed both methodical, in principle, yet unrehearsed and improvised, in practice. Although I never saw it, Lawrence told me that there was an official TurboUK document that outlined a very particular signing procedure which specified who had the authority to sign the contracts, and on which side of the paper. However, in practice, Lawrence admitted that this process could become “very convoluted”. Paul impressed this complexity on me as he described how rushed and improvised the lead-up to the act of signing became for the engineers:

> You can’t really fine-tune it [the act of signing] until probably a week before. So you go, ‘Right, get everyone sorted, get the paper work sorted, get the printing sorted, get that person lined up for signature. Right, where is he [the signatory]? They’re going elsewhere on that date. Right, we’re going to be delayed two days. What effects does that have? Get the courier rescheduled. How does that affect the customer you are trying to work around?’ Then you’re trying to get the papers to him, and he can only sign in the presence of someone, and you’re trying to find your way around the signature rules. It’s all just you learn from the guy next to you. Actually getting it done is even as much of a nightmare as the rest.

Paul found that achieving the signing ceremony in accordance with the rules was a challenging activity because the actual practice enrolled an emergent and unpredictable assemblage of available social and material conditions. His work was being shaped by other actors as much as he was trying to cajole all the elements to align for a signing ceremony. In effect, the engineers were learning that this signing process was a complex network of associations that needed to be managed, but was often unpredictable and unstable. To me, it felt like these were arbitrary rules that could be termed ‘factishes’ (Latour, 1999b) – something that had been so steeped in tradition that they had been turned into matters of fact. Yet these factishes were unhelpful, as they did not account for the complexities and heterogeneities of the signing process in this volatile, fast-paced organisation.

This complexity often positioned the BDM engineers to improvise strategies to overcome delays and implement workarounds that allowed them to “find your way around the signature rules”. It felt as though the engineers’ learning strategies to approach this complexity were limited: they seemed to be ordering their work anew each time through tinkering with the signature rules to get the contract signed as quickly as possible. As Paul mentioned, they looked to colleagues or the ‘guy next to you’ to glean tips on the best way to proceed if there was a delay. However, this constant improvisation may not be an efficient way to learn as the practices to approach these complexities are never stabilised. Yet, as soon as the signature was added to the contract, it immediately began to obscure much of the work that had gone into associating and combining the heterogeneous elements inscribed in its network. In Law’s (2004, p. 20) words, “the materiality of the process gets deleted”. This effect of deletion could impact how the engineers understood and achieved accreditation and validation for their work. An example of this effect of deletion was the bell-ringing practice, which I touched upon at the beginning of this chapter.

The bell (see Figure 13) was rung when the project team obtained a written signature on a contract by the BDM responsible for arranging the contract. Here, the signature was being enacted as a ceremonial symbol, as in a marriage or the signing of a treaty. Fraenkel (2008, p. 21) maintains that this practice is recognised as a performance (as in Goffman’s (1959) dramaturgical sense) because there is an expectant audience to witness the act: “you sign in person, in front of witnesses, and in a certain way. You must recognise the ceremonial act of signing, and more precisely, the celebrations it requires”. In the TurboUK office, the other employees sitting at their desks were the expectant audience.

I liked to think that this bell-ringing was an “extraordinary moment” (Michael, 2012, p. 28), bringing to bear rituals of approbation and celebration. But the jarring gong sound was also acting as a “moment of difference”: in halting the flow of work, it offered an insight into mundane workings (Michael, 2012, p. 28). Paul commented that, in this moment, the bell symbolised a practice like that of “a second-hand car salesman”. I felt this portrayed the notion of success as an individualistic achievement; a victory attributed to the BDM.

However, it appeared to me that the success of ‘winning’ the contract was a distributed and collective achievement. Through my observations and interviews, I had understood the work as a networked accomplishment, which relied heavily on support from numerous heterogenous actors spread across the different departments. It seemed that the bell-ringing could make fragile the networks of cooperation by undermining collective achievements, as Fay remarked in an interview, “as technical support, we’d never be able to ring the bell, you know, we’re still working hard and contributing to successes but we’d never be able to ring the bell in our own right”. Thus, this ceremonial activity appeared to strengthen the networks that positioned certain actors in power whilst silencing or backgrounding other actors’ involvement. Perhaps collective achievements needed to be recognised and made visible in order to encourage distributed cooperation, which seemed to be a crucial knowing-in-practice for the engineers.

Whatever symbolic ceremony was chosen to mark the act of signing, the signature represented the engineers’ professional responsibility to fulfil the terms of the contract, with a guarantee of quality, consistency, liability and safety. They were also held accountable, for example, they could be sued for not fulfilling their agreed terms. Yet, with the addition of the written signature, the collective, messy, contentious effort that I have described was erased, as if only the signature itself counted. Thus, the signature itself was a process of translation.

If translation is succesful, as Suchman (2000, p. 325) argues, the results (in this case, a signed contract) “can be effectively performed as stable artifacts that support the movement of people and goods through time and space”. In Latour’s (1987) terms, the signed contract might be considered an immutable object. However, in the final section, I will argue that this was not the case. Suddenly, the signature was doing other work that took it from its original material moorings as purely a legal document. The signed contract was, in fact, not immutable at all.

Signed, sealed, but still delivering: Working with ‘contracts multiple’

While I found the notion of boundary object helpful to show how the pre-signed contract invited a space to negotiate a shared understanding for different perspectives of the work, once the contract was signed, I felt that the signature was actually ‘doing’ different realties. As with Mol’s (2002) account of atherosclerosis, the signed contract was not only being perceived differently; it was being enacted differently as ‘contracts multiple’. This enabled the signed contract to move into different spaces and different practices. In this section, I conceptualise the signed contract as a fluid object (Law & Singleton, 2005). Similar to the Bush Pump (de Laet & Mol, 2000), the signature was so entangled with other networks that it was impossible to say when it had achieved its aim. It was now acting as “more than one, less than many”, in Mol’s words (2002, p. 55). In the following passages, I engage in analytical inquiry to consider how engineers in each department continued to work with the signed contract as a fluid, different object. This enabled certain practices, which evoked particular knowings-in-practice and learning strategies as the signed contract was performed as a reference tool, a learning resource, a to-do list, a performance monitor, a relationship facilitator and a token of trade.

Once the paper contract had been signed, it was archived in large, locked metal filing cabinets at the back of the office (see Figure 17).

Figure 17: Locked cupboard housing filed contracts

Not one of the participants admitted to accessing the original signed paper contract once it was archived. Instead, the engineers downloaded a digital PDF copy of the contract to work with. Although it had been made manifest absent (Law, 2004), it seemed important that the engineers knew that the printed contract was still there; the inky signature continued to generate reverence from behind locked doors. The entrenched networks that inscribed the contract with its legal power still held strong.

Yet, practices of digital archiving had evoked a different object altogether that helped engineers navigate the contract as a reference tool. As Gherardi and Landri (2014, p. 3) point out, “the autographic signature stimulates also the development of the practice of archiving documents and files and the differentiation among objects of writing in terms of ‘original’ and ‘faithful copy’ (or ‘copy’)”. Scanning machines had been enrolled to translate the signed paper contract into a scanned, PDF digital copy (see Figure 18). This digital file was saved on the shared drive on the company’s internal computer system and available to everyone in TurboUK as an electronic document.

Figure 18: Scanning machines

A member of the Project Support team would have equipped the PDF copy with character recognition software, as Fay explained to me:

> You can run something in Adobe, which means you can search for things like you would in a normal PDF or Word document, because to begin with I was like, 'Oh my god, somewhere in this 600 pages of scanned stuff is the information I need and I won't be able to search for it because it's been scanned.' Oh, no, no, they run the OCR [optical character recognition] so you can just go, 'Ah, is there anything for aviation lights? Control + F, aviation, ah, there it is.

The recognition software had accelerated the engineers' search process of the contract, allowing them to zoom-in on chunks of text that housed a specific clause, for example, on aviation lights. With this addition of the Control + F function, a translation had taken place. This digital materialisation of the contract was acting as a different knowing object for the engineers. Post-signature, the agreements of the contract were now approached by the engineers as matters of fact (Latour, 2004). The engineers were not looking through the contract to amend, add or argue the contents, but they were relating to it as a stable point of reference to check that they were abiding by the inscribed specifications of the legal agreement with their client. The engineers did not need to manually flick through the many pages of the paper or digitally scanned contract. Instead, the zoomed-in chunks of text had become a stand-in for the contract itself.

However, Lawrence believed that relating to the contract with this zoomed-in method was an unhelpful approach for engineers not directly involved in arranging the details of the contract pre-signature. He strongly advocated that the learning potential of a contract was in coming to know it in its entirety, as he discussed with me:

> You get more out of a paper copy, because there's so many linkages between Agreed Requirements, the FIDIC part, the project plan and the employer's documentation. So, unless you actually go through and read it … I always say to the client's engineer, 'Read the contract,' because they're the worst guys. They just think it's a FIDIC contract and it's TurboUK and it's the same and it's, 'Let's just do the same again, the same again,' you know.

This is an example of someone who was fighting the smoothing over, or black-boxing, of the different textures in each unique contract. Digitalisation of the contract may have encouraged the reader to gloss over important nuances. Lawrence believed that in approaching each contract as a unique map, it would help the engineer navigate the many complexities and subtleties between the different human and non-human links in each contract.

The engineers in the project management and service departments were also evoking the signed contracts as a learning resource. Jeremy, one of the newer PMs, told me that he felt he had minimal guidance when he started at TurboUK as colleagues were so busy with their own projects. To learn what was required of him in his daily work, he improvised by reaching for the signed contracts: "So, the first thing I did when I was told what sites I was getting, I went in and started printing off the contracts." Through the act of printing, the contract was re-evoked as a paper copy, but one that was reproduced from a digital scanned copy. Here, the object was acting like a learning manual, or handbook. Jeremy was translating the written contractual agreements into a to-do list of his daily work requirements. For Jeremy, a key knowing-in-practice was how to navigate his way around a very fluid, opaque working environment using the archived and re-accessed contract as his induction tool.

Andy, a service engineer, also enacted the signed contract as a learning resource. He found it useful to refer to old contracts to learn about bad, or unhelpful, practice: “I think it’s good to have an understanding of them because we have such a variety of crap that’s been signed up to, good stuff and bad stuff, bad agreements, bad guarantees”. Opening-up the contract as matters of concern again acted as a learning strategy for engineers to question previous practices, and help them calibrate what had been bad or unhelpful practice in the past.

Andy admitted that he did not know how to navigate contracts before starting the job at TurboUK, and that “you do need a degree in law probably to read these things”. Instead, he had learnt how to read a contract by creating monthly customer reports. The service engineers used these reports to monitor the performance levels of the customer’s built wind farms, measured against the legal conditions and guarantees promised in the corresponding signed contract. Andy stressed the importance of how understanding what was written into the signed contract was translated into a measurable, operational performance:

> You need to know the contract. You need to read it. You need to understand the guarantees. You need to know what we will be penalised for and what we won’t be, and how that’s interpreted by how the turbine is operating.

The contract was acting as a key performance indicator: it detailed for the engineers what had been guaranteed by the project team, and what the consequences were if they did not meet these guarantees. It framed the boundaries of what was acceptable and not acceptable performance of the turbines.

Andy suggested a potential learning strategy whereby new engineers should “help out with the reporting, as it will get them into contracts. It’ll get them using the software. It’ll get them to see how the turbine operates, how the control system operates”. Through working with this entanglement of software and contract, engineers could learn how the contract related to other actors in the operating process, as it unfolded in practice.

How the contract was made present, or manifest, did not always mean a physical presence of a paper copy. A key knowing-in-practice for some of the engineers was to judge which version of the contract to make present, or make purposefully absent, in specific situations. For example, although Walter had showed me that he kept a printed copy of the *Agreed Requirements* in his project folder, he said that he consciously did not make present the signed paper contract during meetings with clients:

> I've seen PMs and they've gone into meetings with the clients, and I'll just go in with my notebook, and they'll go in with their notebooks and the contract, set the contract beside them. I just think that sets a bad tone, aye … when you refer to the contract that's when things are breaking down with the client – 'You need to do this, this and this.' I try not look at them [the contracts].

It was as if the effects of the materialisation of the signed contract were more than the sum of its parts. Although the signed contract inscribed the legalities of the agreement between TurboUK and the client, notions of trust and reciprocity were now more important to their everyday work. There seemed to be an unwritten agreement that there was some give and take in the engineers' and clients' working relationship, which meant that they did not have to consistently refer to the minutiae of the contract. Walter was attuned to this, and had learnt that making the paper contract present in meetings suggested that the relationship was 'breaking down' by undermining the trust they had built up. Brendan, a Technical Support engineer, also described this dynamic with the client, referring to the absence of the paper contract as symbolic of a 'collegial' relationship:

> If your relationship with your client is good enough, quite a few projects we've pretty much gone through without even opening the contract. That's your ideal is to have the collegial relationship with your client. You know, we're not here to shaft you for a load of money, we want to build a wind farm that's good … Once you start going to the contract you've hit a point where you can't agree anymore. There's things when you're delivering a project where you go, 'Ok, I'll let you away with a couple of grand for that,' or, 'If you sort this, we'll sort that out,' but if you're absolutely sticking to the contract and the client is absolutely sticking to contract then you spend so much of your time sending letters, being shitty and not getting the wind farm built … So, at the end of the day, it's just much easier if you can go through the whole thing without referring to it. Shove it in a cupboard and lock it up.

Brendan and Walter had learnt that a collegial relationship built on notions of trust and reciprocity, led to a smoother, and more efficient, working relationship.

Importantly, this relationship allowed for opaque spaces in which trade-offs were considered acceptable practice. Again, these trade-offs were not inscribed in the contract, but required the engineers to make improvised and situated judgements about when to give and take, what to let slide, and when to enforce the legalities inscribed in the (signed) contract.

Chapter summary

In this chapter, by tracing the accomplishment of a signature on a sales contract, I have shown how the signature underwent many translations, and acted as a translation process itself. Firstly, the organising of the pre-signed contract required aligning distributed activities as a key knowing-in-practice, which was mediated by both human and non-human actors. Treating a material constituent of the pre-signed contract (timeline) as a boundary object was helpful to show how fluid, opaque spaces were crucial to allow to negotiate, but not necessarily resolve, different perspectives. Latour's (1999b) notion of factishes highlighted how the act of signing was performed as a socially fabricated tradition, whose 'rules' were at odds with the volatility and complexity of the day-to-day practices. Finally, I showed that once the signature was added to the contract, practices of archiving, scanning, printing and copying invited different ways of working that materialised the signed contract as a fluid and multiple object.

In the next chapter, the work of the signature is still highly prominent as I focus on an organising process that had been implemented in TurboUK to help align the work activities mobilised to accomplish the signature: The Stage Gate Process.

Chapter 5: Flattening the ‘silo effect’

In this chapter, I explore how a seemingly very straightforward process, in principle, emerged in practice as complex, messy and multiple performances: the Stage Gate Process (SGP). Through tracing the different enactments of the SGP, I show how ‘infrastructure’ works in a volatile organisation as a range of informal, uncodified practices that patch together to provide a continuity that is highly fluid. I reveal that the SGP created spaces of tension, deviation, resistance, and ‘looseness’, which had to be consensually negotiated in order to progress the work. The insights I present in this chapter highlight important knowings-in-practice and learning strategies as engineers struggled to align and stabilise infrastructure practices, which required flexibility and variation in enacting everyday work.

The SGP, a project management tool, was of interest because of what it attempted to achieve at TurboUK: flattening what the engineers termed the ‘silo effect’ to create a more collaborative way of working. As exemplified in the previous chapter, the work to secure a signed contract required the gathering of a diverse range of heterogeneous actors. The engineers said that they had previously attended to these demands through a scattered, disconnected and overlapping approach. They would sit in their own little box, or ‘silo’, with their head down, focusing on their part of the task without much consultation with others. When they had completed their assigned work, they would “throw it over the wall”, on to the next person. I assumed that the metaphor of ‘the wall’ meant an obstruction to the flow of information; it obscured the visibility of what decisions had been folded into the work before and after it travelled into a ‘silo’.

The ‘silo effect’ appeared to cause a lot of frustration, and engendered an inefficient use of resources. The engineers told me that senior management wanted to “break down these silos” to create a more fluid and efficient manner of working to achieve a shared goal – securing a signed contract for the sale of TurboUK turbines and their subsequent installation and maintenance. To regulate and order the process of these distributed activities, the SGP was introduced as a prescribed, step-by-step procedure. This occurred a few years before I entered

TurboUK. I will refer to this procedure as a 'protocol' (Timmermans & Berg, 1997). The following figure shows one representation of the SGP (Figure 19):

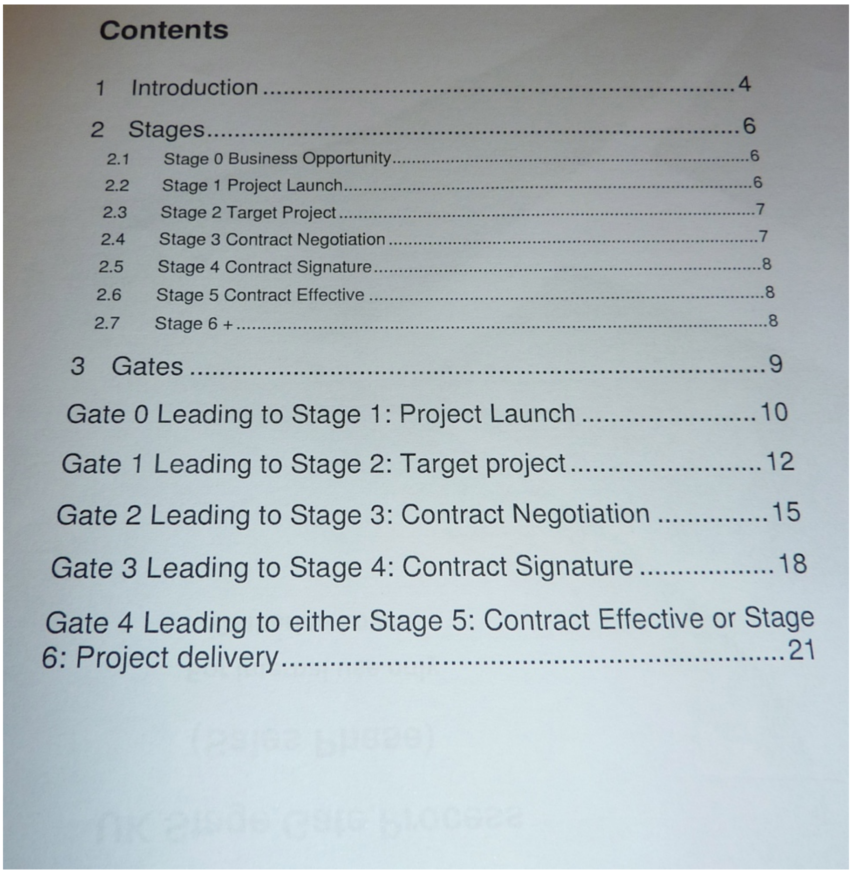


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Figure 19: The Stage Gate Process protocol

This neat, A4 type-written sheet of paper presents a precise and ordered protocol for the engineers to follow. The participating engineers told me that the design of the SGP was to encourage collaborative work between the departments, along a pre-determined trajectory, for example, through the metaphorical Gates 0–6, to ensure proper support was allocated at each stage of the project. It would make work activities more visible through a public process, and thus actions more accountable. However, through my analysis, I discovered that the SGP was far from a straightforward tool that was 'added-on' to engineers' daily work activities. Every day, I observed other work emerging that threatened to destabilise the SGP network.

In this chapter, I will draw on the notions of 'patching' and 'visibility' to highlight some of the different ways in which the SGP was being performed as precarious, multifarious networks that invited matters of resistance, improvisation and power.

I show how these instances evoked particular knowings-in-practice that had implications for engineering education. These include: patching together expertise through different practices of support; exercising professional discretion to calibrate what the range of allowable deviation could be to ‘work-around’ prescribed procedures; calibrating the tolerable range of variation in the ordering of a task; resisting and questioning ‘infallible’ processes; and achieving a sense of stability which allows for the fluidity to tolerate the dynamics of a high-change industry.

In the next section, I explain my rationale for making the SGP present in the analysis. I draw on the notion of relational infrastructure to help frame how the work mobilised by the SGP was emergent, recursive and unpredictable. Finally, I argue why *infrastructuring* is a more useful term to use in this chapter. I now turn to a more detailed description of the SGP’s implementation as a protocol in TurboUK’s everyday work.

Making infrastructuring visible: The Stage Gate Process

During my study, it seemed to me that the engineers were engaged in diverse, yet comparable, tasks over different temporal periods and geographical locations. I noticed that the engineers appeared to be drawing on different disciplines within the organisation, such as electrical, mechanical, and civil engineering traditions, as well as marketing and sales activities. After a considerable period of observation, I could begin to see how these distributed work activities were emerging, albeit patchily, as a coordinated effort. I then started to question *how* these multiple heterogeneous practices, often over-lapping and sometimes conflicting, were jostled together to accomplish this coherent effect, and what this meant for engineers’ knowing.

I was drawn to the organising effects of a project management tool, the ‘Stage Gate Process’ (SGP), which seemed to be a key actor in mobilising this patchy coordination effort. I noticed that the SGP was mentioned frequently in everyday work and seemed tied to key activities of planning, designing and marketing the turbines. Employees discussed it very seriously: they showed frustrations about it ‘blocking’ their work, or referred to it as a panacea to solve disputes. I took a photo of the first page of the SGP and showed it to the participants in their third interview (Figure 19). It created substantial dialogue in the interviews, highlighted by a comment from James, a Business Development Manager (BDM):

> I think the Gate Process would be the most important thing out of all the things I've spoken about which helps me make my work easier because without that you don't get the buy-in of others and you need the buy-in of others to progress.

James was appreciating how powerful a coordination tool it had become in ordering his everyday work.

So how did the SGP work, in principle? I asked the engineers to explain it to me. The idea was to implement metaphorical 'gates' between each stage when bidding for a potential project, obtaining the signature on the contract, building the project, and servicing the turbines. A 'gate' was the term used by the engineers to denote a controlled passage point through which collective decisions had to pass. Again, this could be understood as an obligatory passage point (Callon, 1986a). The department heads created a project team for each potential project,[20] and included engineers from the four different departments. The project team was invited to every Gate meeting. The stages were laid out in a typewritten document detailing what needed to be achieved at each stage, which required a signature by members from each relevant department before a project could progress through the Gate and on to the next stage.

The SGP was initiated to support a coordinated effort that had reach and scope "beyond a single event or one-site practice", and it did not have to be "reinvented each time or assembled for each task, but invisibly supports those tasks" (Star & Ruhleder, 1996, p. 113). These are two of the dimensions that Star and Ruhleder (1996) would argue are characteristic of infrastructure. In this sense, it could be argued that the SGP, positioned as a protocol, was acting as part of TurboUK's infrastructure as it related to its organising practices.

[20] This 'project team' was comprised of a project manager (referred to as a 'PM', from Project Management), a project engineer and an electrical engineer (from Technical Support and Service) and a business development manager (known as a 'BDM', from Sales). A project was considered 'potential' if the engineers considered their turbines a suitable fit, both with cost and technical spec, for the proposed wind farm site.

However, I want to interrupt traditional understandings of infrastructure that tend to position infrastructure as a stable, *a priori* entity, “something upon which something else ‘runs’ or operates” (Star & Ruhleder, 1996, p. 112). I find Star and Ruhleder’s (1996) notion of ‘relational infrastructure’ helpful to start disrupting these understandings, repositioning ‘infrastructure’ as constantly enacted relations of associations, some held in place more strongly than others. Although originating from an ecological tradition, this foray into the relational infrastructure literature is helpful to position the SGP as a gathering of moving, interdependent bits and pieces that are momentarily assembled to support work over space and time. I will now show how the concept of relational infrastructure is helpful for an ANT-inspired analysis.

Firstly, Star and Ruhleder (1996) recognise that infrastructure is more than just familiar, transparent tools, such as power grids. I felt that if I asked the TurboUK engineers to define ‘infrastructure’, they would refer to the concrete materials of the organisation – the things that ensure stability – for instance, telecommunications, wires, datasets, and financial arrangements. I imagine if I started talking to the TurboUK engineers about a different kind of infrastructure, one that comprised abstract entities such as spaces, organising processes, and relationships, they would say, “That’s not infrastructure!” However, in this chapter, what I am trying to show is that this is how their infrastructure was being enacted with them as one of the (human) actors. Showing participants the photograph of the SGP in their third interview (Figure 19), I wanted to follow Latour’s (2005, p. 23) advice that, “the task of defining and ordering the social should be left to the actor themselves, not taken up by the analyst”. I asked them how the SGP helped and hindered their everyday work, which helped make this more abstract infrastructure visible for them.

Secondly, a relational infrastructure highlights the taken-for-granted and often invisible dimension of working with processes (Star & Ruhleder, 1996). Star and Ruhleder (1996) argue that infrastructure “becomes visible upon breakdown”. For example, when “there is a power blackout” (p. 113). As previously discussed in Chapter 3, Latour (2005, p. 81) advises the researcher to attune to “breakdowns”: to look for “silent intermediaries”, which can make visible important ambivalences, disconnections and contradictions in the engineers' everyday work as they resolve these breakdowns. I will be drawing on the metaphor of visibility and invisibility throughout this chapter. This resonates with Law's (2004) presence and absence metaphors discussed in Chapter 2.

Finally, a focus on the relational aspects of an infrastructure emphasises how the mundane relationships between processes, databases, and software packages are not stable entities, but enact certain ways of organising, or ordering, that are not neutral. Infrastructures evolve, change, and are changed by the practices of the people using it (Bowker & Star, 1999). I thus needed to be attuned to this entangled, recursive relationship as I followed the work of the SGP.

However, I still feel the word 'infrastructure' implies a 'thingness' that is counter-intuitive to ANT language. In this light, it may more useful to talk of infrastructur*ing*, rather than infrastructure (Mathisen & Nerland, 2012). Working with 'infrastructure' as a verb, rather than a noun, is in line with Law's purposeful semantic shift from 'order' to 'ordering' (Law, 1994, p. 101). This better depicts an on-going, incomplete and recursive process, which is more harmonious with the assemblage and network metaphors that I have been drawing on so far.

To summarise, the SGP appeared to me as a key actor to follow during my time at TurboUK, and could be argued to form part of TurboUK's infrastructuring in relation to its organising processes. I am advised by both relational infrastructure literature and ANT writings that it is helpful to look for moments of breakdowns to make visible the complexities and messiness of the SGP, and to remember that it is an inherently political, multiple and unstable endeavour. Keeping in mind these characteristics, I will now proceed to show what the SGP process becomes as it passes through the hands of multiple actors. Firstly, though, I consider how the SGP acted as the protocol intended: to make visible and mobilise practices of support to help patch together expertise.

Patching together expertise: Different practices of support

> To be able to sign the contract you can't do it alone, you know, it's vast. It has many inputs that are needed in order to make it complete in terms of all the information that goes in to be assessed correctly and signed by the people who actually sign it.

> So, I guess the gate process is important to get that input from everybody.
>
> James, BDM

In this comment, James was recognising that, to achieve the shared goal of a signed contract, there needs to be multiple ‘inputs’ from a diverse array of expertise, a feat that one person alone cannot accomplish. I am interested in looking at the collaborative process of the SGP as a set of local networks, coming together as a collective, distributed, yet often partial, effort. I will use the term ‘patching together’ to describe this effort.

I observed that this patching together of expertise enrolled different practices of support. ‘Support’ was a key word that kept appearing in my field notes when I observed how the engineers were working together in the project team. For the engineers, the term ’support’ was not being used in an emotional capacity but in three distinct ways: as a sharing of expertise, to work effectively over extended periods of time, and as a governing tool. I now address these practices of support in more detail, describing how they unfolded in practice, and considering the demands they placed on the engineers’ knowing.

1. Sharing of expertise

The first practice of support was the sharing of expertise. As discussed in the previous chapter, a project team was formed when a potential business opportunity was identified. This happened at Gate 0. I was told that the intention of a project team was to allocate various expertise and resource to focus on a single prospective project to align the contract’s material constituents, and then sign the contract as quickly as possible. For example, the BDM engineers often needed the expertise of an electrical engineer to assist them in the contract development, as Paul explained:

> I could progress it to a certain point of the contract [development] but then I’d go ‘right, I need someone on board now like an electrical engineer’. There’s only an electrical engineer who can do most of it.

Paul seemed to recognise that, to satisfy the demands of accomplishing the contract, he had reached the edge of his technical understanding and needed to enrol different expertise. A key knowing-in-practice here seemed to be appraising when to enrol the expertise of others to create a collective understanding, or know-how, of the issue in question. However, many of the participants commented that understanding the different disciplines, those that were not covered in their pre-service education, would be useful to better recognise what the clients were asking of them in meetings, as Paul illustrated:

> A lot of the areas we didn't cover much in mechanical engineering were the electrical side of things, obviously, being mechanical. But having a certain aspect of maybe the electrical side of things, just how generator systems work, would be beneficial … you need to know about how electricity is generated and then how it all feeds into larger network … That was something we were never taught really, you sort of learn that on the job as you go … there was no training through any courses … but I think it would be quite helpful to have that at a previous level.

It seemed that through this need to 'patch together' expertise, the engineers were motivated to expand their learning outside of their HE-qualified technical discipline, as Gary, a Technical Support engineer, intimated:

> What I want to do is get a broader understanding of how the site operates from an electrical perspective, and the different disciplines – the different engineering disciplines – and the civil aspects as well as sales as I suppose it's ultimately engineering as well.

Gary was recognising that 'engineering' practice mobilised a broad and dispersed knowledge base, which spilled into "civil aspects as well as sales". Walter was also concerned about developing a broader understanding of "electrical stuff". He tried to learn from colleagues in meetings but said he could not "keep up because I've not got any background in electrical so I struggle with that", but that he "should really make more of an effort to get involved in that". This raises questions about how workplace, and pre-service education practices, could better support this broadening of engineering discipline education.

2. Bridging support over time

The second practice of support generated by the SGP invited a continuous flow of information that was, for the most part, distributed and strengthened within a designated project team, as Fay, a technical service engineer explained:

> In an ideal world you'd support the same projects all the way through … We [Technical Support] start supporting a project in presales and then the idea in presales is [the client approaches TurboUK], "Ok we've got the site, we're thinking about using your turbines, you know, we're just doing the planning permission at the minute. Can you send us over some documents?" Fine, so we start supporting then, chatting to clients about future projects stage, and then the idea is that the same project engineer and the same electrical engineer will support it through the different gates: the sales phase, through the projects phase, to the handover to service.

This appeared to me as a bridging form of support. Although every action may not necessarily have been aligned, the same people were assigned to the project team throughout its lifespan, so they could continually provide support for each other. The different gates in the SGP were acting as a bridge, in the sense of linking across space and time, to support the activities through all the stages that together comprised one part of this organisation's sense of infrastructuring.

I was aware that the physical space of TurboUK office helped mobilise this type of, often embodied, support. Multiple meeting rooms flanked an open planned office, which seemed to generate face-to-face communication practices. Gate meetings were always arranged in person, bringing together bodies, documents and knowledges. The open-planned floor space invited chance meetings and discussions. For example, PMs would walk over to speak to the Technical Engineers if they needed to confer on a shared project, as this was quicker than waiting on an email. I heard one PM quip to a technical engineer, "I only came for an envelope!" and he had stayed chatting for ten minutes about a concern he had with their project.

3. Checks and balances support

The third practice of support appeared almost as a governing kind of role, which encouraged professional accountability and responsibility for the decisions made throughout the process. I term this form of support as ‘checks and balances’. Brendan, a Technical Support engineer, described this as a way of stopping each person “chucking stuff over the wall” once they had completed their part of the process:

> So if the electrical engineer, if he put stuff in there [the contract specifications], ‘Yeah we can do this that and the other,’ he’s going to be the guy who spends two months in his wellies in the rain looking at some guy painting something blue because he said it was going to be blue.

Brendan was referring to the ‘silo effect’, where each sphere of activity was perceived to be contained and disconnected from the activity before and after. If the engineer just completed their assigned task in the project, and did not think ahead to how it could affect others, there was no accountability for decisions. Furthermore, as it was the same electrical engineer allocated throughout the project, if upstream they had made an ill-considered decision (painting something blue, that probably did not need painting, for example), they would be the ones physically implementing the decision downstream (in their wellies, in the rain).

Lawrence, a BDM, told me that he felt responsible for sharing the tacit information he had accumulated to make sure everyone in the project team understood their responsibilities and the nuanced issues of each project:

> You’ve got a lot of knowledge up here [taps head]. You write a lot of it down but, you know, how do you capture it? ... You go from contract signature through Gate 4, which is the sales to projects [PM] handover, that needs to be the biggest transfer of tacit knowledge, and after that what normally happens is then you‘ve got the kick-off meeting with the client. Different people do it in different ways. I personally view it that until the PM has accepted the contract, I’m not happy to let it go because it’s my relationship, my credibility, with the client that’s important, and ok things happen and things go wrong, you know, tower delivery issues and so on, I can’t influence that. What I can influence is that everybody understands at the kick-off meeting what the deal is, what their responsibilities are, what their roles are, and what the issues are.

As the project moved from sales phase onto the project phase, Lawrence admitted that he could not help with construction issues, but he could provide support to ensure information, often undocumented, was distributed responsibly within the project team and that the professional's credibility was upheld. He was keeping the material trails visible rather than "chucking it over the wall".

Although this check and balance support implies a rigorous and critical scrutiny of the actions taken throughout the process, it was not a formal regulatory process. It was an emergent, collegial support, which encouraged professional responsibility and respect for the following engineers working on the next phase of the project, and to be accountable for their actions in a highly tacit process.

In this section, I have identified three types of support: sharing of expertise, bridging over time, and checks and balances. I felt that these practices, whilst appearing distributed, emergent and informal, and thus patchy, strengthened the original purpose of the SGP. They helped make support practices visible to achieve a collaborative way of working. However, as I now turn to show, although the creators'[21] knowledge was embedded in the design of the SGP, they had no control over how others would engage with it downstream, as Latour (1987, p. 29, original emphasis) predicts, "the fate of what we say and make is in later users' hands". I noticed this phenomenon emerge as the engineers tried to use the SGP in unintended ways to advance local and particular specificities. In the next section, I start to show how tensions in patching together expertise led two different engineers within the same project team to translate the SGP into both a manipulative and a punitive device.

Protocol in practice: Tensions in patching together expertise

> I will try and use the process to help our own cause effectively.
>
> Paul, BDM engineer

This section explores how the original design of the SGP protocol, which was to encourage collaboration and make support practices more visible, also created spaces of tension and conflict. This resulted in the protocol being appropriated in multiple, unintended ways, threatening to destabilise its collaborative intentions. Although the project team shared the same end goals, within their own

[21] In this case, it was Rachel, a head of department, who finalised the design of the SGP for TurboUK's purposes, but a process team in Germany at TurboHQ had originally developed the initial design.

departments, the team members had varying agendas that they wanted to advance. The engineers began to make visible these agendas as they translated the SGP into a different object, as Paul's comment above intimates. As I will now show, this mutability had implications for the engineers' knowing, including engaging in artful compliance, working with multiplicity, and attuning to networks of power.

At face value, the SGP appeared as a transparent tool-at-hand. For example, I asked George, a Technical Support engineer, who had been with TurboUK for about two months, how he was working with the SGP:

> Each gate is just like it says ... The actions you are given are just laid out – what you need to do and what everybody else has to do to make it proceed and succeed – and you know what is expected. So the gate process is something I quite like because it's quite clear.

For any newcomer, it seemed to present as a useful, prescriptive device. However, as Timmermans and Berg (1997, p. 281) point out, "when the protocol is studied as an artefact immersed in practice, more trajectories appear to be affected, and in more ways than is apparent from a bare reading of the text". It is only in the *doing* that the limitations of the protocol emerge, where the user encounters barriers and frustration, and starts to use the protocol in a way that changes it from its original intention, or script (Akrich, 1992). For example, a more experienced staff member, Walter, had a different understanding of working with the protocol in practice. He explained to me:

> It doesnae work. It works in the sales – I've not been to a sales gate for a long time – they follow it up to Gate 4 … Then there's meant to be gates after that, you know, but it's not followed. The handover to service [engineers] is terrible as well. I get quite annoyed with these guys. They follow the spec when they want to and they change the spec when they want some other stuff, and they'll probably say the same about us I'd imagine.

Walter had experienced the limitations of the protocol in that the SGP seemed to fall down a black hole after Gate 4. The PMs were working in a parallel sphere of loose activity until the SGP popped up at the other side, at Gate 7. This is an example of attuning to a breakdown in infrastructuring, where the process started to falter, and the SGP (and its failures) became more visible to Walter.

In another example, Paul described how he mobilised the SGP in practice to enrol extra resource for the BDMs when he needed it to progress a project he was assigned:

> It's a battleground when you're in one of these [Gate meetings], because you're vying for resource, you're pitching your project above others to pick for resource effectively. You're getting your [project] team on board and it gets your project moving. But in doing that, you're doing the opposite effect of it [the Gate process]. You're doing the end result that you want from it to try and push what you want at the start of it. It's a bit more of a selfish view I suppose, but we have targets as a team. Now, the MD hates it when we do that, that we're pushing for the resource and we're using the gate process the wrong way … so it maybe counters the whole logic of how we should be using it [the SGP] but its works it gets the desired result that we need as a business.

Paul was aware that he was not using the SGP as it was intended and, although the MD "hated" that he did it, he had judged that mobilising, or manipulating, the protocol in this way was an acceptable practice because it got "the desired result". This is reminiscent of Suchman's (2000) 'artful compliance', that I discussed in Chapter 2, where she argues that to act competently is at once an 'artful compliance' to collectively acknowledged forms of action, and interminable micro-practices of 'practical subversion', for the sake of just getting the work done. The practical subversion in this performance could be interpreted as a practice of manipulation. In Latour's (1986, p. 273) words, the manipulative subversion demonstrates the "vague notion of power" where power is treated "as the consequence of an activity of enrolling, convincing and enlisting", in this case, through the SGP.

As the protocol worked for one department one way, it prompted other actors to work it another other way, as Fay explained:

> [The SGP] helps us work because there's a certain gate where the sales engineer has a project engineer and an electrical engineer assigned to their project, which means if they come and hassle you before that has happened you can go, 'Well, you know, if it's a quick query fine, but if this is going to require a lot

> work, I'm not assigned to your project yet. If you need somebody assigned to your project now, you need to go and speak to my boss.' So, we can use it to push back against the sales guys, and likewise at any stage, I guess, if they're asking us stuff that seems to be unreasonable and outwith of a task we would usually do we can to use it.

In this scenario, it seemed that Fay and her team in Technical Support had partially reappropriated the SGP to resist the BDM engineers' intensity, almost as a punitive device. Drawing on Akrich's (1992) notion of scripts, Pollock (2005, p. 499) cites a paper by Michael (1996), who "makes the appealing argument that just as we can describe a technology as prescribing one form of use then perhaps the same technology might also incorporate a script that enables its abuse". Thus, as this section has shown, a protocol may not simply embody one script, but 'multiple' scripts. These are often contradictory, as Paul and Fay exemplified. In different actor-networks, the protocol was translated into both a manipulating and a punitive script. This shows that through different acts of translation, the processes are performed as multiple and resistant, and unable to be smoothed over.

A focus on this multiplicity and artful compliance can also help engineers unravel the networks of power that are being performed in infrastructuring. Who/what is being enrolled, enlisted, or convinced to translate the SGP into a different object? Who is invited into the SGP project team? What effect is this having on the engineers' everyday work? Furthermore, issues of multiplicity invite questions about unprofessional or unhelpful practice. For example, Paul had judged that he could manipulate the protocol and use it to secure resource and it was still an acceptable practice, despite the MD 'hating it'. So, when would this tip over into unacceptable practice? How far can the engineers 'bend' around the processes? I now address these questions of reshaping or 'bending' practice in the next section.

Work-arounds: Learning how far to bend

It seems that there is a common belief that the success of making protocols, standards and processes comparable and universal across time and space is due to a rigid adherence to the agreed-upon set of rules. However, observation of practices emerging in the work around the SGP in TurboUK suggested that this rigidity was neither necessary nor actually desired. In this section, I show that the success of working with rules in practice was a result of engineers' professional discretion to judge what the range of allowable deviation could be to 'work-around' the process.

In observing the engineers, I noticed that, although some processes were implemented to encourage 'good' practice, if they were not deemed useful, the engineers tended to skip them and find another, quicker way. Organisational literature tends to talk of these improvisational strategies as 'work-arounds' (Gasser, 1986; Pollock, 2005). Pollock defines a "work-around" as a concept to "explain how one actor is able to adjust a technology to meet their particular needs or goals" (p. 496). Similarly, Bowker and Star (1999) talk of local tailoring to discuss users who develop their own rules to fit their needs.

For those employees who had been working at TurboUK before quality assurance processes had been implemented, they often relied on the 'old way' to get things done. For example, Walter told me that although he supported and appreciated quality assurance processes, he found it easier to arrange things directly with his transport contacts who he had a long-standing relationship with, rather than asking the newly appointed logistics manager in the office to arrange transport. His line manager knew that Walter did this and chose not to say anything, as he knew the work would get done quicker this way. Walter was keen to nurture his direct relationship with the logistics company as he said that they were the people that would help him out if things suddenly went wrong. For example, when recent deliveries were not ready to be picked up at the manufacturers, the drivers waited around for three days until they could be loaded on to their transporters and taken to the storage yard.

This was a useful workaround in that it saved time and resource but at no risk to anyone's safety. However, the use of workarounds invites the question: how far do you bend from the standard or prescribed process before risking safety or violating regulation? Bowker and Star (1999, p. 13) offer a definition of standard as "any set of agreed-upon rules for the production of (textual or material) objects". In the project management phase of the SGP (Gate 4), adhering to health and safety procedures was considered a standard practice. In this instance, the lack of proper procedures or documentation in place could be a serious health and safety risk. George in Technical Support discusses how one missing document could endanger the health and safety of their employees:

> The lifting and loading manual for the Exalt turbines we don't seem to have in the UK right now. So that's a problem for the logistics guys as they've got the components at port just now and they need to know what they're doing. So if they've not got that manual there's a problem. They're either trying to do it themselves – what they think is right – which is a bit dodgy, or they're not doing it, which is costly. So either way just not having a simple document for that is quite either costly or could be unsafe for them.

George was faced with using his discretion as to advise the logistic team whether to override the missing 'simple' document, which materialised a specific process of safe lifting and loading, and save time (thus money), or allowing them to proceed and risk injury. These judgements unfold in spaces that often require a fast decision, out of sight of a manager. Therefore, a crucial knowing-in-practice for the engineers was acknowledging that, while there were rules in place that needed to be followed, the success of working with them in practice was a result of their professional discretion to judge what the range of allowable deviation could be to 'work-around' the standard for different aspects and varying contexts of work.

I noticed that, in these examples, the material traces that helped Walter and Gary makes these decisions were quite visible, local and specific. I was left wondering what happened when these material traces were made invisible in the desire to standardise, homogenise and simplify information and data by using number-based systems, such as ranking methods. The next section explores this issue of representation in more detail.

Representation and resistance

This section explores how the use of metric-based processes, such as databases, to organise work can flatten and eliminate complex issues. This representative practice raises issues of power effects, resistance and a questioning of the infallibility of processes. The following anecdote highlights how these issues unfolded when the service team discussed how to implement standardising processes to accelerate their decision-making. Jason, a service engineer, explained how colleagues in his department developed an Excel-based process to help prioritise the risk-levels of problems with the operating wind turbines:

> So there is such a huge list of things that need dealt with, problems with the turbines. These are called non-conformity reports (NCRs) and are registered as part of a quality assurance process. However, you end up just dealing with the top ten of fifty a week, and so to prioritise the tasks, you end up giving them a number – it's called a QRI number – and it goes up to 1000. So if you have a 900 it will get done, if you have a 100 it probably won't get done … The higher the number, the higher the priority is, so on our Monday morning meetings we look at all our high QRIs.

While I was work-shadowing Jason one day, he showed me how the QRI was configured. A QRI code symbolised a combined score of risk in the equation: QxRxI = Repetitiveness x Cost x Impact. However, if the NCR was connected in any way to a health and safety issue, then it was automatically given high priority. I asked how they established the figures to enter in to a QRI equation. Jason commented that they were very subjective figures so they tried to discuss them as a team before they were added into the database to be as objective as possible. They mentioned that they often found this task very difficult, and that the QRI system was insufficient for representing the complexities of their work. It seemed that the QRI calculation was making the material traces of the decisions that constitute the notion of 'risk' invisible as it translated them into a hierarchical, metric-based system.

For example, Andy, another service engineer, was frustrated with the QRI calculation because, as a rating system, it did not account for the subtleties of the customer relationship and maintaining TurboUK's credibility. For example, the QRI formula used to calculate the risk of the problems caused by a 'noisy' fan at a particular wind farm site, Cathwell, did not equate to a high QRI number, as Andy pointed out:

> With Cathwell's NCR [fan sound], I couldn't have classified that anything other than low, because it is low – financially, health and safety wise, and repetition – it's all low. The only risk is it could harm the reputation of the technology in the UK sort of thing, we don't want the Exalt going into the press as being shut down. So that [QRI] system works in some respects but then it only really covers faults, it doesn't allow you to prioritise other aspects of our work, which aren't on the system.

As I will discuss in the following chapter, Andy had to react very quickly to this noisy fan, negotiating a solution with the council and client, and thus ensuring the Exalt's positive reputation. So, if Andy had relied on the QRI calculation to prioritise his tasks, the Cathwell NCR would have not been attended to and resolved. He had learnt that whilst the QRI system seemed to exert ordering power, and could appear immutable, he resisted being enrolled in it, and used his professional discretion to override this process: he realised that the QRI was not an infallible process.

Finally, another difficulty arises when processes do not function appropriately for the task in question. For example, Fay explains how she wrestled with the design of the database they used to order turbines:

> I had a hell of a problem on a project before because with this particular turbine and tower height combination, it looked like on the database that you couldn't have a lift. I was like, 'But you must be able to have a lift because all our turbines come with lifts,' and my boss was panicking because he was like, 'What if there hasn't been a design for the lift, what are we to do because this has to be on site?' and I'm like, 'It must just be a mistake. Someone must not have put the documentation on the database,' or whatever, and it turned out that was the case … You then get stuff that comes to site and it clashes, there's people having to hacksaw holes in platforms because the cables can't go where they need to go and it's like, 'Nobody checked that this switchgear was compatible with the holes to put the cables?' Apparently not!

On the database interface, there was the option to select certain combinations of turbines and their components using drop-down menus. Once selected, the user was presented with a range of 'extras' that certain turbine combinations were programmed to offer. However, when the database was used in practice, it caused problems for the engineers because the technology had "back-talked", in

Styhre, Wikmalm, Ollila, and Roth (2012, p. 152) terms. That is, “it was not functioning as anticipated in the regime of prescribed technological standards and was instead in need of further investigation” (p. 162). As another actor had not engaged with the database accordingly, it was not allowing them to add certain components (e.g., the lift) or check whether materials were compatible with each other (e.g., the switchgear cables and the platform). The software was back-talking to Fay, exerting power through its black-boxed inscriptions. When Fay realised the system was not working, she had to stop and question its design. Similar to Andy, she realised it was not infallible, and therefore knew she had to over-ride the system to get the combination she needed.

These examples of delegating decision-making to technical processes shows how information and data can end up being homogenised and filtered to fit the system. If this information is forced to fit into a drop-down menu on a database that only offers a select number of options, or is transposed as a number, then this translation can restrict, or hide, complexities and subtleties. This issue is particularly pertinent to emerging industries where rapid innovation and changing policies generate precarious information that resists being represented by pre-defined checklists. Furthermore, this representation has consequences for power, as Edwards and Fenwick (2015, p. 1399) write:

> When centres then translate these resources into representations such as numbers, they can flatten and display them in one space, eliminating their material complexities and cutting their relations of power. Thus decontextualized and reconfigured as non-material, these entities can be calculated in ways that produce hierarchies of advantage.

The elimination and flattening caused by the representation of complex issues with the use of numbers invited engineers to treat processes and databases as matters of concern, in Latour’s (2004) terms, rather than matters of fact. The engineers needed to keep re-opening the design of these processes, making them visible to allow for local contingencies and flexibilities. For example, Fay started to question who had designed the database, and tried to assess where the database, as an actor-network, had failed to enrol the necessary actors (the lift documentation). The engineers’ realisation that processes, protocols and databases were not some pre-existing, invincible system afforded a critical knowing-in-practice for organising work.

Yet, on the other end of the spectrum, TurboUK engineers were faced with instances in their everyday work where the processes were still so undeveloped, so messy, that they had *too* many material traces to follow. Newcomers felt pulled by multiple potential modes of ordering and they were unsure how to move forward. The next section explores this issue of learning to patch together multiple modes of ordering in more detail.

Learning to patch together in loose networks

As TurboUK grew as a subsidiary, engineers were incited to create processes that encouraged standardised practices, such as the QRI, to expedite their work, and "make action at a distance possible" (Latour, 1987, p. 256). Often these were German-based processes mapped on to TurboUK activities. I noticed there often lacked enough guidance, information, and clear direction to bridge between localised (TurboUK) processes and institutional (TurboHQ) processes. It seemed a lot of bridging work, or patching, needed to be done to make the two processes connect to one another. This section explores how engineers struggled to patch together processes when the bridging work between networks appeared incommensurate, and what learning strategies they employed to navigate their own mode of ordering amongst the disconnection.

I first started to notice the incoherence between the German and UK processes when I asked Lewis, a PM, how a new PM would learn about processes at work. Would they be directed to the planning documents on the intranet? He replied with a definitive "no":

> No, no they're rubbish. They're created for a German project, so we should do our own ones [for the UK] but nobody's done it … It's just a really small company trying to get bigger, and it's in that stage where the infrastructure is not there … you like find your own way and resources you've got to make them happen yourself.

It seemed that official documentation outlining the PM's process to construct a wind farm site was written for the German way of organising and had yet to be reshaped for a UK-based process. Lewis intimated that with the lack of clear guidance of the UK processes, he had to navigate and generate his own local way of working. This flexibility can be viewed as inherently characteristic to the success of standardisation. Timmermans and Berg (1997, p. 275) argue that the achievement of universality of standardisation is based on “a certain looseness in the network”. That is, this unsettled state of ‘universality’ is perhaps better understood as one of ‘local universality’. Timmermans and Berg (1997, p. 275) use this term “local universality” to emphasise that “universality always rests on real-time work, and emerges from localized processes of negotiations and pre-existing institutional, infrastructural, and material relations”. They stress that local universality is achieved through association with a *pre-existing* relational infrastructure: new standards and processes incorporate and extend existing routines; they are not created *de novo*. New actors extend and transform the networks, tinkering with them to suit local needs.

However, for the engineers at TurboUK, this was not an easy task. Incompatible process templates designed for the German office were being mapped onto the TurboUK’s activities, which did not reflect the local needs. There were scattered and idiosyncratic ways of doing things, for example, I observed at least three internal software processes being used to document information. This caused confusion when engineers tried to source the latest version of a document without being sure which system had been used to file it. I wondered if the associations between pre-existing relational infrastructures were *too* loose to be able to extend the network. For example, some PM engineers expressed frustration at this level of looseness in infrastructuring, as Jeremy intimated:

> The knowledge of how to build a wind farm is the same but what I struggle with here is there aren’t any processes, there’s nothing documented. If it wasn’t for me speaking to the likes of the other PMs I wouldn’t know what I was supposed to be doing internally like completing work packages. I only heard about them last week that I’m supposed to submit work packages online … at the moment I’m helping my colleague [who was also new], and he’s helping me, so if I email someone about a question I’ll copy him in so he gets the response too.

Jeremy was frustrated that with no clear processes to follow, he was constantly working in an *ad hoc* mode. It seemed that when processes were too opaque or undeveloped, every instantiation of knowing had a high variability and was open to multiple ways of improvising. The notion of looseness here helped redirect my gaze from describing the things in the network, and what they were doing, to that of the sinews of the connections. The strength of the connections in the processes seemed too thin, too loosely stitched together, to make working in a coherent, let alone standardised, way possible.

So how did the engineers move forward their work amongst this messiness and lack of clear guidance? I looked to a new BDM to help answer these questions. Joe had joined just after I had started with TurboUK and was therefore trying to learn the company's processes anew. Joe admitted to me that the work processes all looked so confusing and he was struggling with how to learn amidst so much variation. With no formal guidance, he reached for the prescribed documentation and tools of the relevant processes and databases to read how they *should* be done in principle. He then watched how others related to the processes in practice and noted the differences. When he felt more confident, he began to use his professional discretion to tinker with these processes to create his own rhythm and workflow, as he described to me:

> Since day one I've been kind of shadowing both Lawrence on a specific project he is doing and James on a specific project he is doing. It's quite fortunate in the sense that they were both at the very start of the project when I joined so I've just tagged along to meetings and seen what they're doing and every time they're creating a document or an offer, mucking about with the sales calculator and stuff, I see what they're doing. So through that process I've hopefully seen sort of a linear process of how things work and what needs to be done, which is great, but there are certain process that everyone follows, and then there are certain processes that people do in different ways.
>
> So James and Lawrence work quite differently and so it's not as if I've been doing the same thing on two parallel projects. It's very much been doing it James' way here and Lawrence's way here, which initially is like, 'Fucking hell, which way do you do it, this is complicated,' but I think in the long run it will be good as it shows you what's flexible and you just have to find your own way of figuring out what is best for you in terms of ways of working.

What I understood from this conversation was that when a new person enters an organisation, and they are faced with many different ways of completing, or ordering, a task, they try to figure out which is the 'correct' order to proceed. In Latour's (2005) terms, it could be argued that Joe was creating distance (in his newcomer role) to make the familiar unfamiliar. In doing so, objects, such as the sales calculator, were made visible as accounted and distributed mediators. Eventually he realised that multiple ways of orderings were tolerated, concluding that there was a flexible range within which he could to work. The mediators then disappear again as "invisible, asocial intermediaries … through know-how, habituation or disuses" (Latour, 2005, p. 80).

A key knowing-in-practice emerging here appeared to be a very important calibration about what was the tolerable range of variation in the ordering of a task. The engineer needed to assess when they had crossed a line into doing work that was not acceptable practice, even if other actions that were permissible seemed more illogical. For example, a new engineer may have to work out what they had to do to make sure they did not take more than a day to get a set of documents reviewed. Did they have to complete the last page? Could they confirm delivery schedules by phone or did it have to be on email? Should the forms be completed by hand or typed? The engineer was calibrating that none of these questions mattered as long as they returned the documents in twenty-four hours. Meeting this deadline framed the range of variation that constituted tolerable practice for this task. So how did the engineers learn to calibrate what this range of variation could look like?

Joe mentioned how he had enrolled colleagues as informal mentors to prompt learning, and other engineers told me how this mentoring approach had helped them navigate the messiness. The PMs also talked about another informal learning strategy, which entailed documenting 'lessons learned' so they could be presented to other PMs in the hope of avoiding repeated mistakes, as Walter pointed out to me:

> The idea is you do a 'lessons learnt' report at the end of each project. Before, we'd done reports and my colleague done one and he fell out with [another colleague] about it because she was going though it and criticising it and it's not meant to be like that. It's more like, 'Here's what I've learnt.' So, instead of reports, we were going to do wee presentations, like once a month, so that's

> what we are meant to do if we follow TurboUK processes, but we don't do it because we are so busy.

Walter highlights that, even though they were repeatedly trying to enrol a 'lessons learnt' activity in their department, it continually failed to stabilise. This may have been due to lack of time. The engineers were tumbling from one project to the next, not stopping to consolidate how they resolved tensions or issues in each project. It may also have could also positioned the engineers as being held accountable for their mistakes because once written in a report or on a PowerPoint slide, a positive 'lessons learned' activity could be translated into an admission of failure by colleagues or managers.

Despite experiencing some frustration working within 'loose' networks, the engineers repeatedly told me that they enjoyed having the freedom to find their own way in their everyday work; they were enacting flexible infrastructuring. The next section further explores this flexible way of ordering in more detail, drawing on the notions of tinkering and tailoring.

Tinkering to achieve flexible ordering

In this final section, I discuss how the engineers at TurboUK seemed to enact knowledge practices that balanced a sense of stability with the fluidity needed to tolerate the dynamics of a high-change, volatile industry. In the following quote, Paul reflected on this balance, and what it meant to be working as an engineer in a smaller, emerging organisation rather than a well-established company:

> Do we want to have more processes? Having a more structured process within which you build on and follow those processes, you end up with a company like [competitor's name]: a very rigid company where you have processes for doing each bit of the work: you have processes for payments, you have processes for everything else, whereas here I don't follow the processes that well. I follow it for resource, yes … I think there are many useful processes, but in the whole scheme of things that I enjoy having in a smaller company, I would hate to have that lost if we moved to that larger structure. It would ruin the whole ethos of the

> company that we have here that we can just easily work together and that's why we can be so flexible for other things.

It seemed that while Paul appreciated the need for "useful" processes, he felt the flexible "ethos" of a smaller, growing company would suffer in the face of rigid conformity, a characteristic more common of a larger organisation. It was as if Paul was trying to reconcile how his work could be situated between the "laudatory" status of standards which one "aspires to live up to" and the "derogatory" connotations of standardisation as "the suppression of individuality in the service of industrial uniformity" (Timmermans & Epstein, 2010, p. 71).

Sharon, an engineer in charge of managing one of the company's databases, told me that "I have done well here precisely because it's disorganised". I understood this comment to mean that spaces of disorder held more potential for the engineers to demonstrate their expertise and capabilities, than if they were to be working within "a very rigid company where you have processes for doing each bit of the work", as Paul commented. Thus, the engineers appeared to be not just appliers of existing processes, but also enrolled in networks that afforded them the opportunity to tinker (Knorr-Cetina, 1979; Timmermans & Berg, 1997) with processes to better suit their needs at a specific moment in time. In Law's (1994, p. 101) terms, the engineers seemed to be appreciating that infrastructuring would always be "an incomplete performance of an unknowable number of intertwined orderings", which invited continuous ordering, or tinkering.

For example, the SGP was not perfect. A disconnection seemed to occur at Gate 7, during the PM-to-Service handover, already referred to by Walter. This handover symbolised the shift of responsibility from the PM team upon the operationalisation of the new turbines to the Service team to monitor and maintain their performance. The problem the service engineers faced at this handover was that the PMs tended to move from one project to another without documenting the entire engineering process on paper. Therefore, during the service period, if they could not find out why a decision was made or what had happened at the PM stage, they literally had to "reverse-engineer it" or "wing it". Andy, another service engineer, raised concerns about the strength and usefulness of the SGP due to the lack of consistent and necessary project documentation. Along with a small cluster of colleagues from other departments, Andy decided to revisit and adjust the SGP's design:

> There is a project-to-service handover process but the documentation quality and volume varies project to project. So it's really standardising that and producing document templates rather than leaving it up to somebody to decide what they think, interpreting the process and saying that, 'Well, we need to do that, that, this is what we think we need to do,' and just go, 'Right, these are the documents you need to fill out, there you go.' It makes their job easier too and it means we get the information we need to support the projects for the lifetime that we need to maintain it.

Here, Andy and his colleagues were evoking knowings-in-practice concerned with innovating. By tinkering with this part of the SGP's technological script they had made the process visible again, as matters of concern (Latour, 2004). I was told that this task group was borne out of a local, informal need to address a breakdown in the process, not as a top-down managerial request. Andy and his colleagues thus enrolled more actors (document templates) to make the network stronger, and to tailor it to their needs (ensuring in-depth information of the PM process was documented). This sort of innovative trial and error seemed to be encouraged rather than criticised at TurboUK, but in an unofficial manner. Having this freedom to tinker, and to lead these endeavours, rather than be requested to do so by managers, may have made the engineers feel more connected to TurboUK as an employee.

In summary, I think that Paul, Sharon and Andy were trying to articulate that TurboUK offered them a space that encouraged capacities of adaption, tinkering and creativity. It was a space that seemed to respect local and particular needs, but not at the expense of reaching a shared goal. Thus, the engineers needed to be resilient enough to work in uncertain spaces, as they were often working with processes that were opaque, overlapping and unfinished. They needed to have confidence to explore different modes of orderings through trial and error, to exercise professional discretion to calibrate the appropriate range of deviation from the 'standard' processes, and to assess the boundaries of acceptable practice amongst multiple improvised ways of working. It seemed to me that I was observing engineers enact knowings-in-practice practices that would afford a flexible sense of stability, which allowed for the fluidity to tolerate the dynamics of a high-change industry.

Chapter Summary

In this chapter, I showed that the SGP can support a collaborative way of working, as its design intended. I explored how the SGP evoked practices that encouraged a patching together of expertise through different practices of support, which I termed *sharing of expertise*, *bridging support over time,* and *checks and balances*. However, I also explored how the SGP was appropriated in multiple, unintended ways that threatened to destabilise its collaborative intentions. In these spaces of multiplicity, questioning networks of power emerged as a key knowing-in-practice.

I showed how engineers performed work-arounds and professional discretion to calibrate how far they could deviate from the 'standard' process. I highlighted how number-based, automatic process can obscure the many inclusions and exclusions that occur in infrastructuring processes, which could make processes and protocols appear immutable and infallible. However, I showed how the engineers were attuning to the inherent sociomaterial nature of engineering practice, and had learnt to question these 'immutable' processes as matters of fact. Finally, I showed how the 'looseness' of institutional processes being mapped on to local ways of working created multiple ways of improvising to achieve everyday work.

I concluded by foregrounding the knowins-in-practice and leaning strategies required for engineers to practice proficiently in high-change, emerging industries. This balancing act required a continuous shaping, or tinkering, of the SGP amidst on-going professional judgement of acceptable deviation from the 'standard' and a calibration of the variation of tolerable ways of working. Thus, infrastructuring, and the SGP, were constantly re-enacted in a "consensus-of-the-moment" (Fenwick, 2010, p. 121). However, although the SGP was performed in multiple, resistant and patchy networks, it did support a distributed way of working, as evidenced by TurboUK's success in signing contracts.

In the next chapter, I show how another seemingly stable and inevitable entity – a wind turbine – can be understood as a precarious alignment of social and material relations, which are continually produced and re-produced. I explore how the work to stabilise this precarious 'object' demands particular knowings-in-practice and learning strategies that may not be accounted for in current education practices.

Chapter 6: Stabilising a new technology: The Exalt turbine

This chapter is concerned with analysing engineers' knowings-in-practice and learning strategies as they worked to implement a new turbine technology, the Exalt (a pseudonym), into their everyday work and advance their organisation's goals. The focus of the analysis presented in this chapter is not on understanding engineers' procedural, technical 'know what' knowledge of operating the Exalt as a specific piece of new technology, which will most likely be replaced by a newer, improved iteration in a very short space of time. Instead, I explore how the engineers' practices were being performed to stabilise a new technology. This work entailed mobilising and enrolling many entities that were simultaneously social, political, economic *and* technical, described by Law (1987) as 'heterogeneous engineering'. In this view, for a new technology to become successfully implemented, or stabilised, the networks connecting these entities must be strong enough to resist being toppled by unresponsive or hostile actors.

This presented challenges for the engineers at TurboUK because the work to stabilise the Exalt as a profitably operating product was being threatened by unruly actors such as new arrangements of technical components, noise complaints, pressured deadlines, volatile political bodies consistently reworking renewable energy policies and regulations, and in-house processes that were suddenly no longer fit for purpose. These actors were of concern for engineers working in an emerging industry because they were highly changeable and unpredictable. Furthermore, the assemblages that these actors were performing often prompted novel situations and problems, which positioned engineers in spaces of uncertainty and tension.

In this chapter, I work with the ANT concepts of heterogeneous engineering, assemblages, translation, and matters of fact and matters of concern, to show that the work of ordering, or translating, heterogeneous actors into a stable yet precarious actor-network invoked new and different knowings-in-practice, and specific learning strategies. In the following sections, I describe four different assemblages that were being mobilised to perform the Exalt as a stable actor-network in a specific time and space. The term ‘assemblage’ is helpful here to show that the engineers were engaging with the Exalt, not as a discrete object, but as a fluid network of multiple and precarious heterogeneous actors that were constantly shifting. These four assemblages did not unfold in a linear, sequential order of activities, but were performed as recursive and interdependent phenomena. I introduce the assemblages in a sequence purely as an organising device to present the analysis.

Firstly, I consider an assemblage, which I call *Exalt-as-imagined-possibility,* to explore how the Exalt was acting as an elusive object that was yet to be manufactured, but that was already being framed as a finalised artefact. This required considerable work from all the engineers – not just those in the sales department – to translate its fragility and uncertainty into a convincing commodity that could be purchased by their clients. I term the next assemblage *Exalt-as-a-physical-presence*, in which I explore how the engineers responded to problems and gauged progress as the Exalt turbine gradually presented as a physical entity in a muddy field. The third assemblage I depict highlights the assemblage I call *Exalt-as-finishing*, which explores how multiple performances of ‘finished’ were played out in order to complete the build of the Exalt and secure a government-funded renewable energy subsidy. The final assemblage I explore, *Exalt-as-precariously-stabilised*, maps how the engineers had to negotiate the work of stabilising the ‘finished’ Exalt within a complex, and often hostile, entanglement of environmental, economic, political, educational and cultural networks.

To illustrate these assemblages, I draw on materials that I gathered from observing the daily work of three Exalt projects[22] in different stages of development. Cathwell was a wind farm site positioned next to a harbour and was the first site to erect an Exalt turbine in the UK. Freeshields, at the time of my observations, was awaiting delivery of ten Exalt turbine towers. Craigkenny was a challenging wind farm site based on a remote island. I am drawing on these projects because they provide useful anecdotes that illustrate four over-lapping assemblages that were at work during the implementation, and stabilisation, of

[22] These project names are pseudonyms

the Exalt. Firstly, though, I provide a short description of why I chose to follow the work activities generated to stabilise the Exalt actor-network.

Setting the scene: The Exalt turbine

> I'd nearly compare the wind industry at the moment to the iPhone and Samsung Galaxy, kind of battle wars. Every week a competitor has a new product out or a different power curve or a different sized rotor or a bigger machine, a better machine … maybe every two months or so you get [a competitor] who comes up with something, we come up with something, then another company will come up with something … because it's a growing industry and a growing product base and machines have ramped up drastically from what they were say 10 years ago to what we have now.
>
> Paul, Business Development Manager (BDM)

As illustrated by Paul here, the wind industry was continuing to grow quickly with unchartered hinterlands of technological possibilities still to be explored. Like the mobile phone industry, another relatively emergent industry (Giachetti & Marchi, 2010), the rate of development in the wind industry was characterised by strong competition with its rivals to innovate and produce the next leading technology. For wind turbine manufacturers, this innovation was often centred on the development of cutting-edge turbine technologies and the improvement of their efficiency. At TurboHQ, the Exalt was the newest and largest megawatt-generating turbine and was already in operation in Germany. The Exalt had just entered the UK market as I began my fieldwork at TurboUK. Its timely introduction presented me with the opportunity to follow the engineers' practices concerned with stabilising a new technological artefact into their everyday work.

As with the act of signing the contract, the work mobilised to implement the Exalt turbine created a noticeable energy around the office, and it engaged and enrolled many actors in its effort to become a stable actor-network. Challenges, tensions and unresolved issues emerging from the activities concerning the Exalt were discussed daily in meetings and during participants' interviews. The word 'Exalt' was used so often it felt as though the engineers were treating the existence of the Exalt as a unitary, taken-for-granted object, or, in Latour's (2004) words, it was acting as matters of fact. Yet, when I left, six months later, the energy and tensions surrounding the Exalt were still as palpable as when I had joined. This signalled to me that, from an ANT analytical perspective, it was more helpful to consider the on-going work to stabilise the Exalt as matters of concern (Latour, 2004); to continuously approach the Exalt as an unsettled phenomenon.

I now turn to consider the first assemblage I became attuned to, the *Exalt-as-imagined-possibility*.

Exalt-as-imagined-possibility

> It's a machine that's not even on the market yet. It's not a machine that's developed, but we're trying to sell it. We're trying to get it developed and get it sold for a wind farm which may or may not go ahead so [laughs] so you're selling a product that doesn't quite exist. And it's a huge unknown, a huge challenge. You don't have control of the price of steel. You don't have control of the location of the project, which will reflect on how much the transport will cost. The ship that you are looking to get in 4 years' time, is that available? Do we have to lock it down now? You don't have control of how windy the site is – if it's very windy it's going to cost more to install because you're going to be waiting for the wind to die down. You can't really factor these into pricing so we just have to put our finger in the air. We have to put in a number, give it our best estimate and just put in some margin on top of it for a risk budget effectively.
>
> Paul, BDM

This quote is an extract from one of the many conversations I had with Paul about securing the contract for the sale and implementation of Exalt turbines on a project, Craigkenny, which was four years away from being built. Paul was describing challenges facing the Craigkenny project team as they worked with an object that did not 'quite exist' yet, to convince their clients of its saleability and suitability amidst a particularly high degree of uncertainty. Although this work to translate an intangible promise into a tangible product appeared to be a common sales and marketing practice in industries to remain competitive (Levitt, 1981), I observed a dynamic that I thought was perhaps different to more traditionally organised engineering firms. In this section I highlight that, although the sales department was leading the sale of the turbine, the engineers in the other departments were intricately involved in the sales process.

Despite the unknown variables that Paul listed (wind speed, transport cost, the price of steel and resource availability), the TurboUK engineers needed to appear in control of the contract process to retain the client's trust and confidence until the contract had been signed. The following extract is from my daily notes reflecting on a meeting organised by Paul and the Craigkenny project team:

> Craigkenny is on an island and is a challenging site for a number of reasons. Paul's client wants to purchase the Exalt turbines to populate Craigkenny but the site won't be ready to build upon for a few years' time. However, the pressure and timescale has now shifted due to the National Grid delaying the grid connection to the island for another year. Up until now, the client has been pushing for the signature and trying to hurry the process along but now the power between Paul and the client had shifted. Paul and his team now need to put the pressure on the client to get it signed as the client is no longer in a rush and may in fact start 'shopping' around for other turbine quotes. Therefore, Paul's strategy is to integrate the Exalt turbines as much as possible into the Craigkenny project design so that it becomes too difficult for the client to use a different turbine design from a competitor. To tempt the client to sign, Paul agrees that they will tell the client that they can fix the payment figure for the turbines right now – 'if you sign up now, we can fix that for you'. Therefore, the cost of Exalt turbines will be guaranteed at this year's prices, even if they are not installed for a couple more years. However, the contract will include an amendment of Condition Precedent concerning the grid, that is, if the grid connection fails to happen, the contract terminates.

From this observation, it appeared that Paul and the project team needed to position the imagined technology into an object for the client that could be negotiated, costed, and guaranteed. They did this by mobilising material actors that had been enrolled in previous practices. These included appending an additional clause to the contract to account for grid connection problems, promising fixed-prices of the Exalt turbine to appear generous, and using project design strategies to frame the Exalt as essential to the fundamental design of the Craigkenny site. Paul also explained to me that in their financial modelling they used 'wiggle room' to account for the uncertainty in transport and turbine cost. Paul and his colleagues had thus re-presented the uncertain aspects of the potential wind farm into apparently tangible, 'matters of fact' through several, partial translations. A key knowing-in-practice for the engineers appeared to be tinkering with existing practices to find these partial translations to respond to a new challenge.

As shown in the above extract, the whole project team was enrolled in this tinkering practice. In the following quote, Paul describes a meeting at TurboUK that involved engineers from each department discussing the development of the potential Craigkenny contract with the client:

> The [technical, PM and Service] engineers, you rely on them, on their technical knowledge, but also on their commercial knowledge not to say the wrong things in the meeting where it might bring more scope and more cost into us, and I think you do have to have a level of commercial awareness and an understanding of negotiation and an understanding of the product. Yes, that comes as a given with the engineering role that you're in not to say the wrong thing or to say the right thing or to word it in the correct way that fits what we want and the client hears what he wants.

As Paul points out, it was "a given with the engineering role that you're in" to know what sort of information was acceptable to disclose to clients that would, firstly, not incur any additional cost and work, and, secondly, seduce the customer. I felt that this description of the TurboUK engineering role had more of a marketing or sales feeling to it than would be expected of more traditional, formalised engineering roles. It seemed that Paul was arguing that a key knowing-in-practice for all engineers, not just those who were working in sales, was understanding how the technical value of the product was shaped by its competitive, commercial value to the customer. I call this knowing-in-practice, 'commercial awareness'.

To become attuned to these more commercial sensibilities, the engineers had to learn when not to say the 'wrong things'. They had to become masters of allegory practices. Law (2004, p. 88) discusses allegory as "the art of meaning something other and more than what is being said". By choosing what to make visible, the engineers could artfully delete, or withhold, certain pieces of information about the Exalt's condition that would deter the client. A key knowing-in-practice here was judging when to engage in this process of artful deletion to present the Exalt as a "literal depiction of a single reality" (Law, 2004, p. 89) that painted a sense of assuredness, and attracted the customer without violating sales regulations relating to complete disclosure.

Finally, developing a credible and respectful relationship with the client was a key activity for the engineers to retain their business for future projects, as Paul intimated:

> The main thing is repeat business, get customers in, keep the business, keep working with the customers, try not to fuck it up and just keep them coming back for more business. If we do that by building up good relationships with them, being responsive and being in a position where we answer their questions quick enough or answer them in a way that they need them, it all helps.

Again, this was a concern for all the engineers and perhaps was characteristic of a 'commercial awareness' sensibility. Learning strategies that emerged from this attunement to 'commercial awareness' included responding to customer questions promptly and with affirmative information. Engineers told me that multiple methods of communication were enrolled at this point, such as phone calls, emails and meetings, to strengthen these connections.

If this strategy was successful, and the client had been convinced of the engineers' promises, the contract could be signed, the Exalt turbines could be ordered, and the PM could move forward with the construction of the turbines on the designated wind farm site. As Paul pointed out, the sales engineers were "managing the project from a stage of paperwork through to the completed section of paperwork, and then it goes from paperwork to actual physical live objects". The next section explores how the engineers worked with the Exalt as it became an "actual physical live object" that emerged as the work moved into a different space: the wind farm site.

Exalt-as-a-physical-presence

As the project progressed into the physical construction of turbines in a farmer's field, the assemblage of *Exalt-as-imagined-possibility* translated from a series of negotiations conducted in office spaces via words, quotations, emails, phone calls, drawings and spreadsheets, into a different assemblage of actors, which I call *Exalt-as-a-physical-presence*. The materials and people enrolled in this assemblage moved back and forth via train, boat and car journeys from the office, manufacturing depots, storage yards, and 'site'. 'Site' was where the Exalt began to materialise, in a literal sense, through a gathering of towers and blades, access roads, sub-stations[23], and Portakabins[24] designated as 'meeting room', 'toilets' 'canteen' and 'office', respectively, by large signs temporarily pinned to the doors. Tracing the work of this assemblage, it became evident that the engineers could start calibrating the effects of the Exalt as it was slowly pieced together in muddy fields. The particular knowings-in-practice emerging from this assemblage include anticipating health and safety risks, embodying the perception of progress and professional pride, and organising temporary networks.

I benefited from a trip to the wind farm site, Freeshields, to observe for myself the work practices being performed on site. Clutching a coffee and a bacon roll, I accompanied a project manager (PM), Walter, on a very early morning train journey south, picking up a hire car at the other end to drive to the site. Every few weeks, PMs try to get out to site. Often it is for the monthly 'site meeting', a scheduled time for everyone who is involved in the project to meet face-to-face to discuss progress and provide updates. This was the reason for this visit. On the journey, Walter showed me his project file for Freeshields, which held a print-out of the relevant sections of the contract, diagrams of the met mast (a meteorological measurement tower), and a step-by-step programme written out in Excel and updated monthly for these meetings. He sends this programme the day before to the rest of the attendees via email. He then showed me the notes from the previous site meeting and pointed out other key (human) actors who normally attend[25].

As we arrived at site in the car, plastic signs highlighted a right-hand turning to the wind farm site. The boxy Portakabins, the low-quality signs, and the muddy,

[23] A sub-station is a building, which houses the electrical grid connections.

[24] A Portakabin is a portable cabin rented for a short period to provide a versatile yet secure space.

[25] Key actors at monthly site meetings normally include: the turbine supplier (TurboUK), the construction civil contractors (who are designing the site), an engineer responsible for National Grid connection and electrics, the client (who has developed and owns the site), and the renewable energy consultants (who advise on the site layout and construction).

unmarked tracks, enhanced the temporariness of this site of work (see Figure 20).

Figure 20: Portakabins on site

For me, it felt as though it was a materialisation of a temporary gathering. However, it seemed that Walter was not so struck by the temporary nature and performed the work on site as if it were an extension, or embodiment, of his office. Walter's project file had moved from his office to this other 'office', whose walls were adorned with health and safety print-outs as well as huge charts showing project timelines. These printed displays and documents embodied some of the practices enacted in the office on to site. For me, I felt it was very different, materially, in every sense, from the office, where everything was so neat and clean. The muddiness really brought to light for me this unpolished and harsher space, and I had a sense of stepping into the engineers' own environment a bit more. It made me much more conscious of my presence as a non-engineer, woman researcher.[26]

Before the meeting, Walter had offered to drive me around the site. I had to complete a visitor's health and safety induction at the site office before we drove out on to the work site. This entailed the site manager reminding Walter that he must drive at no more than 15mph, the car hazard lights should be on at all times,

[26] As experienced when stuck in the ladies' toilet on site, see Chapter 3

and, if we got out of the car, we had to make sure all machinery had stopped. I had to sign a form listing my details and emergency contact information. After changing into the compulsory safety gear, a few sizes too big as they are designed for men – high-visibility jackets, steel-capped boots, and a hard-hat – I felt the part, and we headed off at 14 mph to look around the site. Here, my presence as a 'visitor' raised issues of risk that, without me present, Walter would not have had to worry about as much. I was an embodied notion of risk that Walter had to negotiate, and he had learnt to do so by following the site's health and safety requirements.

Walter seemed very passionate about being able to get out of the office to see the effects of his work unfolding in a muddy field and to be able to 'show it off' to a visitor (see Figure 21).

Figure 21: Driving on site

The ten turbine towers were to be put up over several fields. I could see how they were going to be spaced out by the tower foundations already in place. We drove to one of the foundations to take a closer look. It was a circular concrete fixture, rising from the ground to about knee-height, with electrical cable connections crawling like spiders out of the top. It was cold, wet and damp outside of the car. My hat kept slipping over my eyes and the mud was making walking near impossible. Yet Walter did not seem perturbed by the mud or the cold. Perhaps the not-noticing was part of this practice?

After a cursory look at the foundation, I was quite happy to get back in the car and blast the heat. Walter, however, stayed by the foundation for a while longer, taking photos of the spidery cables on his camera phone and grinning like a proud father (see Figure 22).

Figure 22: Walter surveying the turbine's concrete foundation

For Walter, this was the materialisation of the hours of phone calls, emails and compiling documents in the office. He was seeing something different than I was in the muddy fields. Walter explained to me later that coming to site helped make everything 'seem real' for him:

> I think it was more the problem-solving and the practical nature of it, so when you've done everything you can actually look, and there's a project and there's turbines in the ground … I like actually being in a turbine and actually looking around turbines and things.

By looking, showing, photographing and touching the turbine components, Walter's senses were translating the muddy field into an organisational concern: assessing the rate of progress. This progress seemed to prompt a sense of professional pride and achievement. I had also had previous discussions with a service engineer, Andy, about his enjoyment of being on site**.** Again, adverse weather did not bother him, as if it was a taken-for-granted aspect of engineering practice. He told me:

> I would prefer more site work, more hands-on, it's not good sitting behind a computer all the time. I mean I went through a period before I actually got out on the site where I was trying to work out what I was looking at on the drawings, it's a bit different if you've got the drawing and you've got the kit in front of you, so rather than just having it on paper laid out by somebody that has a particular style of doing a drawing and like circuit diagrams – where does that go? It's much easier if you've got it in front of you, and it's just a lot nicer being on site, even if it's raining.

It was as if Andy felt that there was a particular knowing-in-practice that was initiated when the 'kit' was physically in front of him on site. He wanted to experience the kit through physical stimuli and sensory perceptions. This could be termed an "aesthetic understanding", as suggested by Strati (2003, p. 53), which considers how knowing-in-practice, is "experienced and supported by the senses rather than just the way we think". This aesthetic understanding prompted a different knowing than one evoked by a stylised, and perhaps idiosyncratic, pen-and-paper representation of the kit.

This aesthetic understanding has important implications for how the engineers approached problem-solving. For example, Andy told me about an issue of a bouncing platform on one of the towers, as he described to me below:

> An issue at a meeting yesterday is that one of the platforms – because each tower level has a platform – the top platform is bouncy which is a bit of a concern. So, the guy that's having to look into that is basically going from what he has been told by people on site, instead of actually seeing it, and I do think people need to get out and feel it, and actually see it for themselves, it's a lot quicker.

Andy felt that the 'guy' tasked with fixing the bouncing platform would gain a better understanding of how the technology was functioning if he could feel and see it rather than just being told about it from others. Andy had learnt that their bodies needed to be affected by the materials and their relationships to fully appreciate the connections that were performing the *Exalt-as-physical-presence* assemblage.

These experiences on site afforded Walter and Andy embodied and aesthetic engagements; their bodies intermingling with the other bodies (both material and human) on site to feel, hear and see distance, size, weather, noise and concrete.

Following Gherardi's (2017b, p. 209) understanding of affect, I would term these aesthetic-embodied engagements with material relations as 'affective knowing'. Thus, being positioned as an affected body on site seemed to be an effective learning strategy as it helped both Walter and Andy sense and attune to both the flow of work progress and problematic technical issues.

In summary, this section has explored how the engineers were attuning to and responding to the Exalt as it materialised as a physical entity on a wind farm site. Taking me to site as a visitor meant that Walter had to translate practices of health and safety from a numbered representation of 'risk' on a risk register into an assemblage of hard hats, speed limits and flashing hazard lights. Observing Walter on site, physically relating to other people and objects, I felt that he was being affected by a real sense of connection, and attachment, to the client and the product. Both Walter and Andy were enacting aesthetic-embodied engagements with the material relations on site. For example, seeing the spacing between the turbine foundations in the muddy field, feeling the bouncy platform with their feet and knee joints, fiddling with the circuit boards in the turbines, and speaking with other key colleagues, were important strategies for solving problems, sensing progress, and moving the project forward.

Exalt-as-finishing ("with a lowercase f")

The next assemblage I am exploring helps depict how the engineers negotiated the notion of progress and completion of the Exalt to achieve a finished object: an electrically and financially generating Exalt turbine. To be able to progress to the next client's project, the engineers needed to settle the current work into a 'finished' project. Borrowing Latour's (2004) terms, they needed to attend to the project as 'matters of fact'. However, from a sociomaterial perspective, I would argue that a completed state of the Exalt would never be achieved, but would continue to act as a precarious network, constantly being reworked by the elements, technical maintenance, new political targets, financial incentives, and local community support. Like the contract, and the Bush Pump, it was a fluid object with no clear, identifiable point of being 'completed'. Therefore, I have termed the assemblage at work here *Exalt-as-finishing* to denote a process of finishing that allows for continuous and multiple enactments of an implemented Exalt, rather than a single, ‘finished’ state.

In this section, I explore how the work in this assemblage was being shaped by the pressure of completing the Exalt projects in time to qualify for a government subsidy policy called the ‘Renewable Obligation Certificates’, known colloquially as ‘ROCs’[27]. This seemed to result in a need to maintain, and make visible, a fast-paced and consistent flow of work. However, this flow was often undermined by unpredictable disruptions, which the engineers wanted to make less visible to their clients and colleagues on the wind farm site. Managing this tension had implications for the engineers’ knowing, including attuning to and interpreting conflicting timelines, using considered discourse practices to temper news of delays to clients and contractors, juggling of resources to maintain constant flows, and manipulating the multiplicity of the concept, ‘finished’.

Questioning yet another acronym, I learnt that ROCs were a nation-wide subsidy policy set annually by the current UK government to encourage licensed electricity suppliers to produce renewable energy. Paul explained to me that each obligation period ran for one year, from 1 April to 31 March, and every year the subsidy price was reduced slightly. Therefore, he said, TurboUK’s clients – energy suppliers – made the most of their yearly allowance to maximise their profit as they were unsure when the ROCs would reduce to a rate that made wind farm development unprofitable.

[27] Renewables Obligation Certificates (ROCs) were introduced by the UK government in 2002. These certificates are tradable commodities that are designed to stimulate the construction of large-scale renewable electricity in the UK and to entice various stakeholders to invest in this sector. The ROC ‘requires licensed UK electricity suppliers to source a specified proportion of the electricity they provide to customers from eligible renewable sources. This proportion (known as the ‘obligation’) is set each year and has increased annually’ (DECC, 2013, n.p.). Therefore, this policy directly affects the supply and demand of energy that needs to be produced by emerging renewable energy organisations. As of 2016, ROCs have now been replaced by a new funding system called ‘Contracts for Difference’.

I noticed that the approaching deadline of 31st March 2013 coincided with an increase in the energy and pace of the participants' daily work. Exploring this connection further, I understood that TurboUK employees needed to finish installing the turbines for their clients by this deadline so that the client could benefit from their ROC allowance, and for TurboUK to maintain their positive reputation as a leading turbine supplier and installer. Interestingly, TurboUK was not contractually responsible for meeting the ROC's deadline; they were only responsible for following their agreed project plan (an internal process). I asked Walter what would happen if they did not build the wind farm by the end of March. He explained:

> Nothing contractually, we will just get hit by LDs – liquidated damages – which is £500 quid a turbine a week or something like that, which isn't massive for us but it's more client relationships. The company I'm dealing with they've only ever had TurboUK turbines, and they told me they only ever want to have TurboUK turbines. It's good but this will put it under a lot of strain if we miss, the guy told me if we miss it, it will cost them six million, and they're not a massive company.

Walter had realised that the incentive to meet the ROCs' deadline outweighed the project plan's timeline because failure to do so would mean losing the client's trust and business for future projects. Any plateauing of workflow in the lead-up to March was equated to a negative state: delays meant incurring liquidated damages and damaging client relations. Therefore, Walter, and other engineers, had learnt that there was always more than one completion date in circulation at any one time. A key knowing-in-practice was how to prioritise specific timelines over others and gauging the effect this would have on their relationships with clients.

However, there was always a possibility that the flow of the project work would suddenly and unpredictably cease, jeopardising the targeted deadline. Furthermore, it was not a singular, linear flow of work that was circulating in this assemblage, but multiple flows of work, all partially connected to the *Exalt-as-finishing* assemblage: for example, securing scarce resources, manufacturing delays, and changing transport routes, were flows that overlapped and jostled the progress of the *Exalt-as-finishing*. Another key knowing-in-practice for the engineers appeared to be attuning to these multiple flows and their points of disruption.

Yet it was more than just an attunement; they needed to resolve the disruptions whilst at the same time reassuring the client that the project momentum was still being actively managed. A knowing-in-practice that emerged in this delicate relationship development was managing the unpredictable pace of work during the implementation of the Exalt whilst portraying an impression of steady progress, which would result in a completed project by the end of March to meet the ROC's deadline. I noticed two learning strategies that were enrolled to account for the unpredictability of the multiple flows and disruptions: premeditated discourse practices, such as the use of silences and carefully chosen words, and the use of workarounds to secure resources.

When I was on site with Walter at Freeshields, I noticed that he had learnt to smooth over a serious disruption to the flow of work by mobilising considered discourse practices. There had been on-going delays at a manufacturer in the production of turbine towers that had affected the entire wind energy industry and the site meeting attendees were keen to hear updates from Walter about the tower deliveries for Freeshields. Before the meeting, Walter mentioned to me that they would want to have some good news to "give them some confidence", as the delay had a knock-on effect for the other contractors' work on site. As he predicted, the meeting chair pressed Walter for exact dates of the delivery so he could alert the local community about possible traffic disruptions. Walter thought carefully about how he phrased the delay update, stating ambiguously, yet truthfully, that there was "no exact news on further delays". He went on to reassure them that they had a representative at the tower factory keeping the pressure on, stating, "We've got eyes down there full-time". This anticipated use of careful word choice was similar to Paul's explanation of negotiation work in the previous chapter, and the act of artful deletion presented earlier in this chapter. Deploying certain opaqueness was a useful, but delicate, knowing-in-practice to balance full disclosure (which may cause anxiety) with vague optimism, and thus appear reassuring.

Another disruption to the flows of work could be caused by lack of available resources, such as transportation or turbine components. I discovered that, to meet the requirements of the ROC policy with their stretched resources, the engineers looked for workarounds. A workaround, in this instance, is an alternative practice that enrols a different set of relations than ones materialised in the agreed project plan (Pollock, 2005). For example, each project team was trying to secure the cranes, the lorries and the appropriately trained people for their project. They would phone or email their usual contacts to book these resources for a specific date but, if they were unavailable, they would have to quickly source new contacts, or ‘steal’ their colleagues’ booked slots. If one site was delayed for any reason, yet the turbine components had already been shipped and were in the storage yard awaiting delivery to site, a project manager could ‘steal’ these components for another site that was ready for construction (see Figure 23). This generated extra work but Walter told me that he would rather juggle the orders and get one site under construction than have two sites inactive. Therefore, a key knowing-in-practice emerged as an agility to deftly move the materials and resources around to meet each project’s timelines without leaving any site lacking key materials.

Figure 23: Turbine components awaiting delivery from storage yard

Although this juggling was a seemingly accepted and informal process, there seemed to exist an uncertainty about which resources were available until the problem arose. Suddenly, the very substance of the object – the towers – could come part of two or three other turbines, collapsing this notion of 'finished'. Attuning to the appropriate timing to take this action seemed to be an essential knowing-in-practice in order to maintain the flow of the project, and achieve a finishing that was perhaps not in the original project plan.

Another workaround enacted by the engineers was to re-interpret the March deadline as the need to commission the turbines, not necessarily to complete their work on site by 31st March. That is, the engineers were tasked with making sure the turbines were connected to the grid and generating electricity by the end of March. They re-interpreted this requirement loosely by ensuring that one turbine on each of their client's sites was connected to the grid, as Fay explained: "so that's the turbine up and finished with a lowercase f as opposed to an uppercase F as it's still not all been done". There were different conditions of 'finished' that the engineers had learnt to negotiate. The engineers would still have to commission the rest of the turbines on each site, tie up loose ends and conduct inspections, but with one turbine generating on each site, they could satisfy the ROC conditions and settle the project into matters of fact. Therefore, the engineers had learnt to translate the policy to suit their time-pressured needs by transforming the object from 'Finished' (with an uppercase F) into two different 'finisheds' (with a lowercase 'f').

This section has shown how knowings-in-practice were enacted to manipulate, coordinate and work around the flows of work to achieve multiple performances of a 'finished'[28] project for the sake of satisfying the conditions of the ROCs. In this complex network of heterogeneous actors, I have shown that it is not helpful to separate out the natural, technical and social factors that affect the flows of the project. Instead, they enact an intertwined, heterogeneous system, as described by Law (2011a). I will return to this notion of 'flow', drawing on Law's (2011a) work, and what it portends for TurboUK engineers' professional knowing in the following chapter.

Once the Exalt had become an operating, physical entity with its imposing blades beginning to turn in the wind, the engineers were faced with new challenges. I understood that the success of the Exalt's performance did not just rely on the 'finished' implementation of a resolved artefact into a muddy field, but was instead positioned as "ongoing practices of assembly, demonstration and performance" involving gatherings of multiple actors and continuous negotiation (Suchman, Blomberg, & Trig, 2002, p. 163). The precarious shaping, coercion and taming of these multiple actors and relations, I argue, is what Law (1987) would term 'heterogeneous engineering'. Thus, the successful implementation, and continuing stability, of the Exalt as a new technology was a precarious achievement in the face of potentially opposing forces and contradictions that had to be endlessly convinced and negotiated. The *Exalt-as-a-physical-presence* assemblage, discussed in the previous section, can now be understood as an assemblage that I have termed *Exalt-as-precariously-stabilised*.

[28] Although, as I have argued, the stabilisation of the Exalt was always in a state of on-going work.

Exalt-as-precariously-stabilised

In this section, I explore the particular knowings-in-practice and learning strategies that were evoked to successfully stabilise the Exalt as a continuously performing, yet precariously materialised, actor-network. In this section, I foreground 'sound' as an actor and show how it was translated into a hostile force - 'noise' - by a local community and threatened to destabilise the Exalt's performance. Sound is used here as an emblem to illustrate how a single issue can evoke a multitude of different and complex perspectives that are in conflict. I show how sound was not only understood differently, but was performed differently by various key actors during the Cathwell project in order to further their own interests. As I will show, this had implications for how the engineers identified and fixed problems, how they mediated the public imagery of the Exalt, and how the negotiation of sound/noise positioned them in tension with the local community and their client.

Once the Exalt had been erected by the PMs, service engineers often took over to ensure its maintenance. The engineers were treating the Exalt as an object that was now fulfilling its intended function – producing kilowatts of energy that fed into the National Grid. However, despite the many calculations and simulations conducted on paper and computers to model the working turbine, the effects of the Exalt's performance were still unknown because it was part of a complex entanglement of environmental, economic, political, educational and cultural networks. A key knowing-in-practice was an awareness that the stability, and thus success, of the Exalt was still fragile and unpredictable, even though it had been physically constructed as a concrete entity in a field.

In line with Suchman's (2005, p. 381) view that "'new' technologies comprise reconfigurations, extensions and other modifications of elements already in circulation", Jason, a technical engineer, was aware that the Exalt was made up of standardised, tested components. Yet he also appreciated that, until all these bits were assembled together, he would not know what effect would be produced. Jason described this unpredictability to me:

> They [Exalt] are all made of components that are quite standard. It's the putting together from a component level that's new. It's

> standard components, and they have warranties and, you kind of know what failures might happen with them. It's just when you put everything together you want to be able to predict that but sometimes things happen that are a bit of a surprise I think, because it's just all about the connections between them and how they work. So I think that becomes a bit less predictable.

Jason talked about this convergence between theoretical and technical understanding and practical application as a "surprise". The engineers were being positioned here by an unpredictable translation that could threaten the stabilisation of the Exalt. For heterogeneous engineering to be successful, Law notes that "vigilance and surveillance have to be maintained, or else the elements will fall out of line and the network will begin to crumble" (Law, 1987, p. 114). Thus, systems had to be put in place to monitor for these possible surprises. For example, Andy, a service engineer, pointed out that the performance of the first Exalt to be erected in the UK, on the Cathwell site, needed to be observed for any unpredictable effects:

> It's a new industry so the newer technology is not tried and tested for that length of time anyway, you can run all the simulations you want on a model but once you stick that out in a complex terrain, a windy site, I mean the [new Exalt] is right on the coast, on the beach and it's going to be battered with salt spray, so we'll see how that affects it.

The translation of the sea salt spraying the Exalt's components had the potential to act as a destabilising force. However, as this section will explore, it was not only the sea salt that was performing as an unpredictable actor in this assemblage. A breakdown at Cathwell afforded me an insight into the challenges faced by the engineers when the stabilising of the Exalt was being threatened by a hostile actor: sound. Andy explained the issue to me:

> We've had some problems with a new turbine at [Cathwell]. The customer has had noise complaints, the customer is a pretty difficult guy so been doing a bit of an investigation into that problem.

The Cathwell site was a very important site for TurboUK. It was acting as a showcase for the advancement of TurboUK's newest technology. Andy emphasised the commercial motivations behind demonstrating a new technology with regards the public imagery: “it’s a different kettle of fish because we need to get an Exalt in the UK to start selling these things”. Andy appreciated that the Exalt, labelled with the title of “the biggest onshore turbine in the UK”, would attract media attention, both positive and negative. He told me:

> As it’s the first one in the UK we didn’t want it being shut down, ‘cause it’s been in the press for being UK’s biggest onshore turbine at the moment, so you don’t want any bad press.

The engineers seemed to understand that the addition of wind turbines throughout the UK countryside was a highly controversial and contested issue. The sound levels of the rotating blades remained a sensitive issue that often received a negative public reaction.[29] National newspapers often reflect and materialise the tensions that new technologies create in political and environmental spaces.[30] With the sound being enacted by the councillor as a hostile actor of ‘noise’, ‘bad press’ could act as a threatening force to the Exalt’s stability. Therefore, it could be argued that the *Exalt-as-precariously-stabilised* was enrolled within a network of public imagery and media, which was embroiled with highly charged political and environmental forces.

I observed how the engineers appeared to be attuned to the political sensitivity of the public’s acceptance to wind farms as part of their everyday work. For example, one of the first documents that I was handed was a brochure designed for community groups that addressed “Common concerns about wind power”[31] (Centre for Sustainable Energy, 2014). This included a section explaining residents’ experience of sound and ‘noise’, with data justifying how turbines were not as “noisy” as a “car at 40mph from 100m [away]” (p. 25). Here, the notion of

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[29] For example, see the Noise Abatement Society website: http://noiseabatementsociety.com/campaigns/wind-turbines/

[30] Different political agendas and ideologies are often argued through the championing or damning of wind farms, depending on the newspaper’s underlying political agenda. For example, *The Express* chose to report one Conservative member’s opinion: ‘The Prime Minister understands why many people do not want wind farms on their doorstep; they are often noisy, unsightly and can push down house prices’ (Hall, June 6, 2013). *The Guardian* printed a more positive spin: ‘But landscape, like language, is constantly, gloriously in transition. It does not stay still. And to me, as I hope to a gathering many, the wind turbine stands as a symbol of a new and respectful intention towards the Earth’ (Barton, April 18, 2015).

[31] ‘Common concerns about wind power’ https://www.cse.org.uk/downloads/reports-and-publications/planning/renewables/common_concerns_about_wind_power.pdf. This document was included in the employees’ induction pack.

sound was translated into noise level statistics to frame wind turbine sound as ‘acceptable’ sound.

Working with the operation of Exalt at Cathwell, Andy had to learn how to respond to the complaint of ‘noise’ in light of the Exalt’s public image and the available published evidence on wind turbines and sound. Therefore, it was a priority for Andy’s work that the turbine operated smoothly and avoided any negative publicity due to faulty operating. Although there was a marketing manager within TurboUK who specialised in PR issues, Andy and other engineers felt that it was part of their professional role to protect the public image of their work. Therefore, prioritising work issues that were subject to media sensitivity emerged as a key knowing-in-practice.

The first concern for Andy to respond to was how he positioned himself to best understand and solve the problem behind the councillor’s noise complaint. I asked him what his first action was:

> Andy: I went down to complete the initial investigation on site …
>
> Jenny: did you manage to fix it?
>
> Andy: … yeah I actually fixed something! ... a couple of plugs were round the wrong way, it just meant that the control system on the transformer fan was reading the wrong temperatures the way it was set up, so it meant it was activating the high speed part of the fan that cools it more often and it is a bit noisier. There had been some complaints about noise from people round about because it’s very close to houses. The council went down to have a look. The complaints from the locals would be related to noise from the acoustic noise of the blades rather than the transformer fan, as you would never be able to hear that from the other side of the water. So the councillor, not knowing what he is talking about, goes and stands on the top of the steps – the bottom of the turbine – and the fan comes on. The transformer exhaust is above his head, says he nearly got blown down the steps, said it’s like a big hairdryer, and it’s escalated from there. Complaining it’s a statutory nuisance noise. So it’s like someone having a party and then shutting it for being too noisy. No planning conditions or anything like that come into it, they were just threatening to shut it down. The thing is, I put the fan on manually, and I walked 15, 20 metres away from it and you couldn’t really hear it so I knew it wasn’t the fan, but the fact that he stood there and said, ‘This is what it is.’ There was something wrong, but

> there will be no difference in the noise they can hear across the water where the houses are. You only learn that by getting in about it and working with it.

As in the previous section, Andy felt he needed to be bodily engaged with the problem: to see the distances between the houses and the Exalt and hear the sound "by getting in and working with it". He felt that it was imperative to travel to site to experience the sound of the turbine and fan in its "being-in-use" (Strati, 1999, p. 27), as though he wanted to insert himself (for a moment) into a specific assemblage 'on site'. I then asked him how he worked through the problem. Andy answered:

> Just trying to work out what's happened based on what you can see visually on the turbine, what you can measure there and what you can get from [in-house software] data which is usually your starting point before you go out to identify what could actually be wrong, and then you go out to site.

The data modelled on software alone was not sufficient for Andy to understand the issue. As it was for Walter, being on site afforded Andy an affective knowing-in-practice, which allowed a convergence of theoretical modelling, with visual and sensory appreciation.

Another concern for Andy was negotiating the many different enactments of noise/sound and the practices entangled in these enactments, and which to make visible, or foreground. Although the engineers knew that the design of the turbine had taken into account the measurements for acceptable levels of sound produced by the Exalt, they had been unable to predict how others would experience this sound at this particular site, as Andy explains:

> Basically, none of them [the councillors and locals] understand how turbine noise propagates – well I never when I started, but I learned how it propagates and what causes it.

TurboUK engineers often told me that people understood sound as a subjective experience and therefore engineers and the public interpreted the level of acceptable sound differently, often translating the effect of the turbine sound into the subjective phenomenon of 'noise'. Wagner, Bareiss, and Guidati (1996) contend that sound can be construed as 'noise' if the receiver identifies it as 'unwanted'. Haggett (2012), a researcher in sociology of sustainability, points out that, "'noise' is experienced in other ways than just acoustic measurement such as 'annoyance' (rather than just noise level), quality, frequency and tone of the noise, interference with daily activities and perceptions of wind energy" (p. 153). She goes on to explain that "noise is being evaluated in the context of the source from which it arises and the situation in which it is being heard" (p. 168). That is, expectations of sound are in turn mediated by the cultural moment. For example, if the wind farm site had been poorly planned, or relations with the local community had been fractious from the start, the noise annoyance could be experienced as greater than if the development of the wind farm site had been enacted more harmoniously with the community.

Paul, the BDM assigned to this project, explained how the Exalt had replaced several older machines on site:

> with one machine, and it gives twice the power of all the seven combined and so that's how steep it's gone up in a curve of technology and improving the generation.

Walter told me that he thought the bigger, and perhaps more imposing, tower could have led people in the community to experience it as noisier. Yet Walter and Andy were confident that the sound levels emanating from the turbine were not exceeding the sound levels stipulated as acceptable in the contract. Therefore, it could be argued that it is not just that the sound is enacted differently in person as it is on paper; it is experienced differently for different people, at different times and places, looking up at the same whirring turbine. Here, the particular knowing-in-practice concerned how the engineers responded to the different experiences of sound in order to convince, or tame, the resisting forces (negative media, complaining council, unhappy residents). They had learned to do this by responding with credibility to the councillor's noise complaint to retain the client's trust for future projects, to ensure that they fulfilled their responsibility to the community for health and safety concerns, and to maintain a positive public image for the Exalt.

To respond with credibility to the noise complaint, the engineers had to reconcile their understanding of how sound was being enacted as a knowledgeable practice of engineering (acceptable sound levels as determined by the industry standard guidelines, measured in decibels) with maintaining a harmonious relationship with the client and community. A key knowing-in-practice emerging in this balance seemed to be the fostering of good relations with the community and client. I observed that this was enacted by an acknowledgement and acceptance of an issue through email and phone call discussions, a courteous response to assure the client that they were receptive to these complaints and would respond in a timely manner, and, if possible, would fix something on the turbine to reassure the public that they had engineered a solution. Although this response was not within their contractual duties, they were very aware of the precarious reputation of wind farms within both the local community and the customer base, as Andy intimated:

> [the client] is on one of those wind focus groups for wind turbine customers … we don't want him going there where all the utilities will have their representatives going, 'Oh, TurboUK has this noisy turbine,' so it's a bit of a sensitive one.

They also responded to this complaint by travelling to site to inspect and test the turbine's working components. Being an embodied engineering presence on site seemed to be a reassuring statement to the public that the complaint had been taken seriously by a professional. Inspecting the turbine at Cathwell, Andy had found that the fan to cool the system was coming on more quickly than it needed to. Andy could fix this fault. Walter told me later that he was relieved because he could then report a solution to the client. However, he knew that the actual noise of the fan has not been reduced and that TurboUK were well within their contractual agreement for acceptable sound levels.

The work Andy and Walter had to achieve here was keeping the client happy by responding to 'fix' a problem, whilst being confident that they had satisfied the industry standard regulations and that, if the council continued to complain, they did not have a legal argument to stop the turbine working. The engineers therefore were not trying to negotiate with the community and the client; they were trying to figure out how to tell them the matter was closed, without appearing antagonistic or uncooperative. Andy summed it up to me:

> Somebody needs to grow a pair because I've done a lot for him [the customer], because at the end of the day the turbine was sold, it's what he bought, it's within limits, it's operating as it should, we went overboard to help him.

This led me to consider how a professional group of engineers have come to know that they could officiate the turbines' sound levels as an 'acceptable' phenomena. What did they refer to? In this case, the engineers had been satisfied by the results from the official measurement tool, 'The assessment and rating of noise from wind farms by the Working Group on Noise from Wind Turbines' (known as the ETSU-R-97), set out in the government's *Planning Policy Statement 22 on Renewable Energy*. However, Haggett (2012) argues that, when unpicked, the scientific method of the ETSU-R-97 embeds several issues that render it inadequate for the task: it is out of date, designed for turbines in the mid-1990s; it has an implicit political agenda that supports the construction of wind farm sites; it does not measure low frequency; and it does not detect vibrations. Walter and Andy were not the engineers carrying out this measurement assessment. It had already been folded into the contract as a completed task at an earlier stage by the developers of the project during the environmental impact assessment.

However, in enacting the official measurement methods as a particular construct of sound, the engineers were performing the ETSU-R-97 as a collateral reality (Law, 2011b). That is, a reality that gets enacted incidentally and quietly along the way. The questionable method of the ETSU-R-97 was not explicitly discussed or debated by the engineers in their everyday practice, but quietly worked to frame what was being argued more overtly – that their turbine met the acceptable sound level requirements in the contract. Law (2011b) argues that it is these collateral realities that are most powerful and harder to undo as they are less visible for contestation. Therefore, for a community group, this official measurement highlighted by a professional group of engineers may have held more power in shaping how sound was being experienced as 'acceptable' against their petitioned complaints.

In this section, I have explored how engineers were learning how to balance the political subtleties of sound as a hostile actor within the *Exalt-as-precariously-*

stabilised assemblage. They seemed confident that their knowing of the ETSU-R-97, which materialised as a contractual clause, supported their legal rights of the turbine's sound levels. Yet what was unpredictable was how the effects of these complex assemblages of media attention, communities, sea spray, house location, 'noise' and councillor complaints would position the engineer to use, or bend, the regulations to firmly close the issue so that they could move their resources on to the next project. As professionals, it was thus their responsibility to contain the consequences of this unpredictability within certain limits. Knowing what this limit should look like, and what materials to enrol and make visible to constrain this unpredictability, seemed a key knowing-in-practice for the engineers.

Chapter summary

In this chapter, I have shown that a technology does not successfully establish itself because of its intrinsic technical characteristics alone, but is continuously performed through a constant negotiation of social, political, economic and technical entities. Sometimes these entities helped to stabilise and sustain the work of the Exalt, but they also worked to undermine it, creating spaces of tension and resistance. I followed the translations that occurred within four assemblages so that I could highlight particular knowings-in-practice and learning strategies that appeared to be key for professional engineers working to stabilise a new technology in a highly volatile, emerging industry.

In *Exalt-as-imagined-possibility*, I showed how commercial awareness was a key knowing-in-practice not just for engineers in sales roles, but for engineering practice in general. In *Exalt-as-physical-presence,* I highlighted how embodied and aesthetic engagement are important dimensions of knowing processes, which can strengthen social and material conditions for problem-solving, and sensing progress. The *Exalt-as-finishing* assemblage showed how important it was to maintain a flow of work, which required jostling, swapping, and reinterpreting materials resources to achieve a temporary sense of 'completion'. Finally, in *Exalt-as-a-precariously-stabilised*, I showed how the on-going stability of the Exalt was a precarious achievement, that required constant negotiation with external forces, and enacting knowings-in-practice more traditionally associated with marketing and public relations.

Chapter 7: Discussion

> [I]t takes effort to sustain stable networks of relations… It is necessary to carry on enacting the network of relations that holds them up and constitutes them. Otherwise, things start to lose their shape, lose their characteristics and seep away. They stop being the objects that they were. Nothing is fixed and forever in the ANT world. Only some things are fixed, and for a time.
>
> Law & Singleton, 2000, p. 336-7.

As I argued at the beginning of this thesis, looking in detail at how everyday practices unfold can inform how education practices can be assembled to support students and practitioners for work. In this analysis of professional work in an emerging industry, I have shown that engineering practices can be understood as gatherings of sociomaterial performances, characterised by multifarious tensions prevalent in today's complex world. Knowings-in-practice and learning strategies emerge as on-going, situated, and materially-mediated enactments in response to balancing these tensions.

In Chapter 4, I showed how the act of signing a contract was a complex accomplishment involving the alignment of many heterogeneous material constituents. The signature itself translated multifarious networks into a stable entity for a moment in time, before it was then enacted as different objects to frame the boundaries of what was acceptable, and not acceptable, practice.

In Chapter 5, I explored how a networked understanding of infrastructuring practices, such as the Stage Gate Process (SGP), unsettles more common ideas that practices, and the powers they exert, are in full control of humans. I showed how the SGP was not performing as a straightforward prescriptive protocol, but instead as multiple, complex assemblages. These sometimes supported a collaborative process, but also extended, transformed, and cajoled the SGP to perform other ways of working.

In Chapter 6, I worked with the concept of heterogeneous engineering to explore the challenges facing engineers' practices in the stabilisation of a new technology, the Exalt. I showed how four over-lapping assemblages of the Exalt were being performed in the engineers' everyday work, and how the stabilisation of these assemblages required flexibility, adaption and improvisation to maintain the flow of work. In all three chapters, I showed how engineers were performing knowings-in-practice, such as commercial awareness and affective knowing, that were not necessarily accounted for in current education practices.

In this chapter, I now shift the focus from tracing and describing the engineers' practices to discussing the pedagogical insights for education practices that emerged from this study. I have shown that a relational, networked understanding of knowing has been helpful to illuminate the material, contested and often taken-for-granted dimensions of engineering practices, and to conceptualise knowing as being performed as knowings-in-practice. From a pedagogical perspective, as Fenwick and Edwards (2014, p. 38) highlight, ANT concepts "offer ways to intervene in the practices of knowledge-making and representing, not theories about what to think". Thus, it may be helpful to envisage pedagogical approaches for education practices that encourage modes of intervening and disruption, and appreciate complexity and mess. These approaches could thus account for, and support, the knowings-in-practice and learning strategies that I observed being enacted in one organisation in a volatile, high-change industry.

Introducing a 'dynamic stability' sensibility

In this chapter, I present a sensibility that I argue could inform such an intervening and disruptive pedagogical approach, which I have termed 'dynamic stability'. This 'dynamic stability' sensibility emerged from my findings and was foregrounded by adopting an ANT approach towards untangling the engineers' work practices. When reading across Chapters 4, 5 and 6, I was struck by the effort and intensity of work that was performed to enact the stabilisation of objects. This was not just the stability of large, new technologies, such as the Exalt that I discussed in Chapter 6, but also the taken-for-granted 'things', such as infrastructuring processes, such as the Stage Gate Process in Chapter 5 and the traditions of signing a contract, which I explored in Chapter 4. As intimated in Law and Singleton's (2000, p. 336) quote above, "it takes effort to sustain stable networks of relations". This effort seemed even more intense in an emerging industry where processes were still evolving, and competing networks were highly volatile and unpredictable. Thus, I propose that this ‘dynamic stability’ sensibility encapsulates the knowings-in-practice and learning strategies that shape, and are shaped, by the tensions and activities I observed being enacted in TurboUK to maintain this precarious stability amongst so many volatile and competing forces.

I consciously use the word ‘sensibility’ here as I want to denote an attunement, a sensitising, towards action. ‘Attunement’ is more than just noticing or attending to something. It is a relational word, a proactive *doing*. I use Fenwick’s (2014, p. 44) definition of attunement as “participating more wisely in particular situations” through cultivating the ability to “attune to minor material fluctuations and surprises”. This helps position educational approaches that support a ‘dynamic stability’ sensibility as developing awareness towards the minute negotiations that are continuously being performed between human and non-human relations, which are often hard to explicate, frequently informal or uncodified, and thus remain backgrounded, or absent from formalised education practices.

Conceptualising and questioning how this ‘dynamic stability’ sensibility speaks to, supports, opposes and furthers existing scholarship and theoretical concepts will guide my exploration of the following three research questions:

Research Question 1 (RQ1): What tensions are professional engineers negotiating as they work in a volatile, high-change, emerging industry?

Research Question 2 (RQ2): What knowings-in-practice and learning strategies are evoked by these tensions?

Research Question 3 (RQ3): What are the pedagogical implications of a practice-based, sociomaterial understanding of engineers’ everyday practice for pre-service education and workplace settings?

In the first section, I address RQ1 by conceptualising four key tensions that I noticed were prevalent in engineers’ everyday work. These tensions were continuously reshaping the contours of the professionals’ work, while at the same time being reshaped themselves by the engineers’ practice. This supports Evetts’ (2011) assertion that contemporary professionalism is defined as balancing multiple, competing demands. For the engineers to enact competent knowing, they needed to constantly negotiate these tensions in increasingly interdependent and innovative, yet partial and multiple ways. In explicating the four tensions, I draw on the following concepts: logics of market and professionalism (Evetts, 2012); Ellström's (2010) practice-based innovation; Latour's (1986) ostensive and performative views of the social; and Mol's (2002) notion of multiplicity.

To address RQ2, I discuss and conceptualise four key dimensions that emerged in the analysis of engineers' knowings-in-practice and learning strategies. I propose that these four dimensions characterise a 'dynamic stability' sensibility. These include: networks of power, opaque spaces, and the mediating role of objects; practice-based innovating; responding to flow; and interdependent practices. While there have been some moves towards recognising these dimensions in engineering education and practice literature, I argue that my findings further advance these dimensions in light of a practice-based, sociomaterial perspective. I work with two key concepts, 'patching' and 'flow', as well as drawing on previous empirical and theoretical scholarship, to extend these dimensions and illuminate some pedagogical concerns arising from these considerations.

In exploring RQ3, I discuss how a 'dynamic stability' sensibility could inform education practices concerned with pre-service education and workplace settings in volatile, emerging industries. To do so, I draw and expand on the four dimensions presented in response to RQ2, and consider the implications for pedagogy. These include: navigating loose networks and multiple flows; dwelling comfortably in uncertainty; supporting practice-based innovating; appreciating the mediating role of objects in networks of power; and cultivating a patching of knowledgeable practices.

Addressing Research Question 1: Negotiating tensions

In this section I address RQ1: *What tensions are professional engineers negotiating as they work in a volatile, high-change, emerging industry?* In the three previous chapters, tensions emerged that were interwoven throughout the activities that I was describing. These tensions were not unique to each activity, but permeated throughout engineers' everyday work. The TurboUK engineers themselves seemed very alert to, and quite comfortable amidst, the conflicting accountabilities. Their main concern was enacting knowings-in-practice and learning strategies to balance these tensions and negotiating which ones needed to influence particular decisions at particular times.

In this chapter, I have selected four tensions to discuss in more detail, although there are likely to be other tensions that I have made absent, or othered, in the study. I was attracted to these tensions because they related to some of the issues in current professional practice explored in Chapter 1. The four tensions included balancing: commercial objectives and client needs with traditional engineering concerns such as health and safety; acceptable practice with allowable deviation; standardising practices with innovating practices; and visibility with invisibility. In the following section, I summarise these tensions in relation to previous scholarship and theoretical discussions.

Commercial objectives and client needs with traditional professional engineering concerns

Balancing the commercial needs of the organisation as a profit-making entity with professional engineering concerns appeared to be a key tension for TurboUK engineers. The engineers were pressured to fulfil a guarantee of service of their engineering work to society (ensuring quality design, adhering to health and safety concerns, honouring product warranties, and appeasing public concerns), whilst at the same time serving the employer's aims. These aims were not only about completing the engineering work, but were also concerned with making profit, retaining clients for future business, responding to advancements in policy and regulations, and rivalling competitors' products and services. This tension could be referred to as a balancing between the logic of professionalism and the logic of the market (Evetts, 2012; Fournier, 2000).

This tension often materialised as a conflict over time and resource allocation. For example, in Chapter 4, I showed how tracing the Project Contract Evaluation timeline as a boundary object was a helpful example to show how the tension between the logic of market and logic of professionalism was negotiated in the engineers' practice. Although the engineers did not seem to question the premise of "client as sovereign" (Leicht & Fennell, 2001, p. 106), they did question the practices of their own colleagues in trying to progress the project too quickly. Thus, the timeline acted as a boundary object, calibrating the commercial objectives of the organisation with those practices of the more traditional engineer concerned with ensuring health and safety, quality and risk.

Williams and Figueiredo (2014, p. 176) note that one of their participants, a CEO of a start-up company, said that his role was like maintaining an "eco-system in which the needs of the client, firm and team members are finely balanced". I draw on their quote here because, similar to the TurboUK participants, the CEO did not view the tensions between different actors as needing to be resolved but to be balanced instead. However, it is important to point out that the work to balance these tensions in TurboUK was not just attributed to senior management but emerged in each of the participants' accounts, regardless of their position. So, as Fournier (2000) and Evetts (2011) argue, it is not about resolving the competing logics, but accepting that this *is* the contested landscape of current professionalism. Client (and market) demands and team members' professional values need not be addressed as mutually exclusive, nor, as Fournier (2000) highlights, does the over-deterministic analysis of market logic necessarily herald the unmaking of the professions. She contends that "the logic of the market shifts rather than eliminates boundaries and this may create new divisions upon which the professions can (re)construct themselves" (p. 81).

Pedagogically, this tension raises questions about how education practices could account for engineers' professional knowledge as contingent and performative, rather than static and fixed. Fournier (2000, p. 83) argues that, "professional knowledge is malleable and expandable, it is constitutive of its field of knowledge rather than bound by it, it may contain the possibility of being reconstituted to claim broader, newer expertise which map onto concerns of enterprise and the market". That is, rather than treating professional knowledge as an independent reality of the engineering field, it may be more helpful to look at what is actually unfolding in engineering practice as relational performances. Thus, professional knowledge could be appreciated as a contingent achievement sustained *by* professional practice and knowledge. Questions being raised for educators from this tension become not which knowledge account is more important to develop (for example, commercial awareness is not superior, or inferior, to ethical awareness), but how knowledge accounts circulate, and what work do they perform as they do so (Fenwick & Edwards, 2014).

Acceptable practice and allowable deviation

The second tension highlights how engineers were constantly negotiating what constituted ‘acceptable’ practice, and how far they could then deviate before it became harmful, unproductive or even illegal practice. At TurboUK, I observed acceptable practices being enacted as following prescribed processes (e.g., the SGP) or sanctioned directives by senior management and professional bodies (e.g., following the FIDIC legal conditions inscribed in the written contract, see p. 112). However, in the analysis, I also showed that ‘acceptable’ practices unfolded as uncodified and informal ways of working. These were performed as workarounds to the more formal processes (Pollock, 2005) or tinkering (Styhre, 2009) to fluidly adapt the process.

Here, it is perhaps helpful to draw on Latour’s (1986) differentiation between ostensive and performative views of the social, as explained in Chapter 2. I illustrate this concept by drawing on the example of the engineers’ practices when signing the contract, as explored in Chapter 4. Although I did not see them, I was told that there were ostensive, prescribed rules delineating how the contract should be signed. If they read these rules, it may be assumed that the engineers could demonstrate what Gherardri and Landri (2014, n.p.) described as, “knowledge about the practice of signing [as] anterior to the situated practice of signing”. The engineer is thus assumed to have learned this knowledge as part of their workplace training.

However, in observing the engineers’ everyday work, I recognised the practices mobilised in the signing of the contract echoing what Latour (1986) calls a ‘performative view’. As I showed on page 126, Paul, a BDM, found he had to improvise strategies to overcome delays to the signing ceremony. This unfolded in almost theatrical performances, for example, when Paul had to quickly organise a man in a van to drive the contract signature page from York to Milan so that it could be signed in person. This anecdote is insightful because it foregrounds how the materiality of the practice (van, paper, traversing continents) shaped this emergent, performative practice.

Although this may not have been a smart use of financial resources, it was deemed an ‘acceptable’ practice at TurboUK because, for the collective, it seemed crucial that the signing of the contract was done in person, pen on paper. This supports Suchman’s (2000, p. 313) view that competent knowing is demonstrated through “practical ‘subversion’, taken up in the name of getting the work of the organisation done”. Therefore, if the practices of signing were considered as performative – as emergent and situated – rather than as existing independently as formalised rules, the act of signing could be understood as a social fabrication where “a professional collective knows how to perform a signature as a knowledgeable collective action by maintaining a common orientation and assembling materials, people, and activities” (Gherardi & Landri, 2014, n.p.). As Latour (1986, p. 273) might say, the act of signing as “acceptable practice” was being “performed through everyone’s effort to define it”. The movement between ostensive and performative required a continuous shaping of practices amidst on-going professional judgement about what constituted allowable deviation from the prescribed, ostensive rules.

In exploring this tension, I have shown support for scholarship which argues that the notion of knowing-in-practice is enacted as ‘collective know-how’ that is a local, situated, and material temporary achievement (Gheradri, 2009b; Orlikowski, 2002). From a pedagogical perspective, this tension is useful to tease out because it highlights that if students and practitioners are taught ‘about’ rules and processes as prescribed ‘objects’, important relational and situated knowings-in-practice that emerge from a performative reality may be over-looked in education practices. For example, acknowledging a performative reality in education practices could entail how students and practitioners evaluate the ethical implications when making decisions about how far to deviate from 'acceptable' practice, and what the consequences of this might be for different networks.

Standardising practices with innovating practices

The third tension highlights how performing standardising practices positioned engineers in an on-going balancing act between innovating and stabilising processes. For a new organisation to grow in an emerging industry, there is arguably a need to develop standardising practices, to allow for what Latour (1987, p. 191) would term, "action at a distance". At the same time, spaces to innovate, work-around or tinker with these processes are necessary to accommodate a high-change, unpredictable environment.

In working to stabilise new or developing standards, processes and protocols, I observed the engineers reaching a tipping point. In an industry that was so high-change, they seemed to need a wider range of deviation from the standard than perhaps a more established organisation might. Standardising practices that were in place, and seemingly fit for purpose six months ago, were suddenly no longer appropriate due to rapidly changing technologies and constantly developing and shifting demands from economic, cultural and political forces. Furthermore, once protocols had been introduced and enacted in practice, the protocol's ostensive design often faltered. For example, Walter found that the Stage Gate Process fell into 'a black hole' between Gates 4 and 7 so he worked parallel to the SGP in another, unprescribed sphere of activity (p. 149). As this range of variation from the ostensive rules grew bigger and bigger, it started to destabilise the purpose of standardisation.

I find Ellström's (2010) notion of practice-based innovation useful to conceptualise this tension. As described in Chapter 1, practice-based innovation refers to the dynamic of balancing the logic of production with the logic of development. The logic of production focuses on "how the explicit work process is reproduced and realized in actual practice" (Ellström, 2010, p. 32). The emphasis is on stability, predictability and efficiency. In ANT terms, if the engineer does not engage in innovating practices, but carries on working with the process as it is, they would be acting as an intermediary (Latour, 2005), transporting the process without translating it, and thus reinforcing the status quo. This strengthens standardising practices and enhances the power of specific networks.

The second logic, the logic of development, focuses on renewing ways of doing an activity through continual transformation, or tinkering (Stryhe, 2009; Timmermans & Berg, 1997) to respond to the volatile environment, which promotes different knowings and doings. It encourages variation, and heterogeneity, whilst embracing instability. In ANT terms, the actors in the process become mediators again, translating and transforming it as it passes through different actors' hands. It is at these points of translation where new and alternative learning opportunities emerge. I noticed that more energy seemed to be generated around this second logic of development, rather than trying to remain in equilibrium with the logic of production. Perhaps this was a characteristic of a volatile industry.

Therefore, positioning this tension between standardising and innovating practices as enacting practice-based innovation raises pedagogical questions about traditional understandings of innovation as a systematic, linear and predefined procedure. This has implications for how 'innovation' is taught in education practices. Rather than a focus on the individual creating a new product or process, students and practitioners could be encouraged to attune to innovation as 'tinkering': an on-going, situated, and, I argue, material, performance. This addresses Suchman and Bishop's (2000) concern that this modest understanding of innovation is often taken for granted by practitioners. 'Innovation', then, should perhaps read as practice-based 'innovat*ing',* which supports the semantic reconfiguring of the words *infrastructuring, knowing*, and *ordering* that I have highlighted throughout this thesis.

Visibility with invisibility

The final tension explores the interplay between assemblages that were being made visible, or foregrounded, at specific times and places, and those that were being made invisible, or backgrounded. Issues of visibility and invisibility are inherently tied up with issues of multiplicity. As I showed in my findings, engineers' practices produced not only different perspectives towards an object, but multiple assemblages, which enacted objects in different ways. In Chapter 4, I showed how the signature's multiplicity was central to the ways in which it worked as a fluid, multiple object, which could be made to speak in different ways for different audiences. This supports some ANT writings, which argue that "practices produce chronic multiplicity" (Law, 2007, p. 13). Thus, negotiating which multiplicities to make visible and which to make invisible appeared to be a constant challenge that was entangled with regimes of power.

For example, in Chapter 6, when the client and local community at Cathwell had to be convinced that the Exalt turbine was emitting sound levels that were registering within the acceptable levels stipulated in the contract, different assemblages that performed the signed contract could have been made visible, or foregrounded to settle this tension. One assemblage included the contract as an artefact of contract law, which stipulated that the Exalt turbine sound levels were operating within the official measurements, specified by the ETSU-R-97 (see p. 191). If this assemblage was made visible, the effect could undermine the client's trust and relationship, jeopardise future business, and incite potentially negative media attention. To avoid these effects, another assemblage, which did not include the contract, but enrolled polite emails and phone calls, embodied engineering presence on site, and fixing a 'noise', was foregrounded instead.

This tension thus raises questions about the choices and options on offer when there exist various versions of an object to perform and make visible or invisible. Law and Mol (1995) would argue that the questions emerging from this tension then becomes: which version, or multiplicity, has the most value? And what is at stake when a choice between these multiple versions is performed? For example, the positive reputation of the Exalt and future business was at stake if the contract was made visible as an artefact of legal power. This multiplicity raises pedagogical concerns around how practitioners can be supported to work within and through multiplicity through a relational network sensibility. Perhaps this might be centred on developing students' criticality towards evaluating which assemblage should be made visible, at a specific time and place, and assessing its potential effects.

In conclusion, I have outlined four generative tensions that drew my attention to how both human and non-human actors were co-constituted in negotiating everyday work*.* I observed that the balancing of these tensions was a complex and recursive interplay between different human and non-human actors, connecting and disconnecting in multiple assemblages. Although these tensions seemed to be enduring, how significant the tension was, and how it played out in the engineers' practices, seemed to be highly fluid and changing. Foregrounding how these tensions were negotiated and balanced through being continually re-enacted in practice is thus helpful for how education practices can begin to conceptualise professional knowing and learning as situated, enacted and materially mediated knowings-in-practice.

Addressing Research Question 2: Attuning to a 'dynamic stability' sensibility

In this section, I build on discussions raised from addressing RQ1 to now answer RQ2: *What knowings-in-practice and learning strategies are evoked by these tensions?* In Chapters 4, 5 and 6, I highlighted knowings-in-practice and learning strategies that were being performed in response to the tensions described in the previous section. These knowings-in-practice included: commercial awareness, affective knowing, workarounds, tinkering and local tailoring, attuning to multiplicity, negotiation strategies, managing flow, patching of distributed support and expertise, and navigating and questioning networks of power. The learning strategies I observed being enacted included: informal mentoring, embodied and aesthetic engagement, calibrating multiple ways of improvising, and observing 'the guy next to you'.

I now turn to discuss what I have termed a 'dynamic stability' sensibility. I propose that this sensibility encapsulates the key knowings-in-practice and learning strategies that I observed being enacted in the TurboUK engineers' everyday work to achieve a continuity, and stability, which is highly fluid. My use of 'dynamic stability' is not to be confused with the engineering concept of dynamic stability, which is used to understand flight motion in instances of disturbance. Nor is it mimicking Teece, Pisano, and Shuen's (1997), concept of 'dynamic capability'.

‘Dynamic capability’ was coined by Teece et al. (1997) and is a popularised concept often referred to in management and organisational literature. Teece et al. (1997) proposed this term to conceptualise a strategic perspective that was focused on creating and maintaining competitive advantage in rapidly changing environments by centring on intangible assets, such as knowledge and skills. However, in a critical review of ‘dynamic capability’, Ferdinand, Graca, Antonacopoulou, and Easterby-Smith (2004) point out that this concept ‘black-boxes’ knowledge as a commodity, and reinforces a managerialist epistemology that knowledge can be ‘sold’ as currency in the knowledge economy. They also stress that the socio-political dynamics that underpin knowing and learning ‘construction’ are often overlooked in studies that discuss dynamic capabilities. I developed ‘dynamic stability’ sensibility in response to Ferdinand et al.’s (2004, p. 14) assertion that “researchers need to be sensitized further to the need for new methodological tools for studying dynamic fluidity in processes and practices”.

Whilst I am leaning towards the notion of flexibility and adaption that the dynamism in ‘dynamic capability’ espouses, the focus of ‘dynamic *stability*’ is on knowing *in practice* rather than on the management of knowledge as a resource. I have worked with an ANT-inspired methodological and theoretical approach to suggest an understanding of dynamic fluidity in processes and practices that can account for complexity, non-coherence and relationality, and which can tolerate the fluidity of a high-change, volatile industry.

I present four dimensions of ‘dynamic stability’ that I believe warrant highlighting and further interrogation and conceptualisation in light of existing scholarship. These include: networks of power, opaque spaces and the mediating role of objects; practice-based innovating; flow; and interdependent knowledge practices.

Networks of power, opaque spaces and the mediating role of objects

In engineering practice and organisation literature (e.g., Adams & Forin, 2014; Boujut & Blanco, 2003; Koskinen & Makinen, 2009), it is often argued that the shifting role of objects creates collaborative spaces, which promote shared, or common, understanding. These findings portray a sense of cooperative working as being enacted in spaces of visibility and harmony. For example, Adams and Forin (2014, p. 119) extol “the need for building common ground, trust, shared ownership and allegiance towards a worthwhile goal”. However, whilst I agree that these characteristics are necessary for collaborative working, I argue that the shifting role of objects also promotes opaque spaces that afford conflicting agendas to co-exist, and that allow for negotiation of power relations to unfold. This negotiation of power relations in these opaque spaces is a key knowing-in-practice for a ‘dynamic stability’ sensibility. In this section, I draw on the notion of visibility to highlight two examples of these opaque spaces within the organisation: negotiation strategies with clients, and the appropriation of the Project Contract Evaluation (PCE) timeline as a boundary object.

In support of Ekstedt’s (2009, p. 21) claim that, “negotiations are becoming one of the major elements in the permanent activities of project-based organising”, I too found that the performance of negotiations was a key activity for engineers at TurboUK. However, although I found that whilst these spaces of common understanding needed to be established, certain opaqueness was necessary for the success of negotiation. There appeared a constant balance between what was made visible and what was made opaque during the negotiation process. This supports Bechky’s (2003) findings, where she linked this need for opaqueness to issues of power and control. In her study of engineers, she argues that, ‘[f]or drawings to be powerful as a tool to maintain occupational jurisdiction, they must be somewhat unclear to other groups, because if every aspect of their work was easily codified and understood, engineers would be unable to maintain their status as experts’ (p. 735). For TurboUK engineers, a key knowing-in-practice appeared to be how they mobilised multiple, layered realities, for example, this more opaque, ‘second level’ of negotiation. They needed to judge what, and when, to make visible, artfully delete, or withhold, but not at expense of violating sales regulations.

Akkerman and Bakker (2011) point out that it is often tempting to think of boundary objects as positive mediators of cooperation, and is one that is often taken up in studies of boundary objects. However, I found the notion of boundary objects (Star & Griesemer, 1989) useful to show how consensus does not need to be reached between two competing actor-networks for collaborative work activities to move forward. In fact, it was in these spaces of disagreement and disconnection that issues of power were negotiated and afforded activities to progress within a ‘dynamic stability’.

For example, when completing the PCE, I showed how a timeline acted as a boundary object to make visible, and influence, different agendas. Although the PM and Technical Support engineers resisted the stabilising of the timeline, the engineers were still cooperating, moving forward the work of accomplishing the signature. The active role of the timeline helped calibrate the commercial objectives of the sales engineers with the health and safety considerations of the PM and tech support. This reflected the negotiation between the logic of market and professionalism described in the first tension that I addressed in RQ1. Therefore, I argue that the shifting role of objects can create opaque spaces that afford a loose or slack space for negotiations of different tensions to be performed.

Practice-based innovating

In this section, I argue that practice-based innovating, based on Ellström’s (2010) work, is a key knowing-in-practice in enacting a ‘dynamic stability’ sensibility. This discussion is central to the third tension described in addressing RQ1. Here, engineers were being positioned to negotiate a space where they could reduce variation and encourage reproduction (the logic of production) while at the same time support transformation and embrace variation to allow for the fluidity of the volatile industry (the logic of development).

Ellström (2010) contends that innovating “begins with a questioning, a disturbance or the emergence of a problematic situation in the conduct of a task” (p. 36). In my analysis, I showed many examples of technologies or processes directing engineers’ practices in particular ways. However, due to the volatility and uncertainty of the environment, as well as the lack of complete or validated information, engineers were often left struggling to move forward with their work.

A key knowing-in-practice emerging from the analysis was questioning and disturbing the processes, and thus attuning to the mutability, or fluidity, of objects. For example, in Chapter 5 (p. 153), Andy, a service engineer, realised that the QRI was not an immutable process. The objective calculation QxRxI had black-boxed the subjective decision-making of what constituted 'risk' into matters of fact. When Andy realised the Cathwell fan incident would be translated into low priority by this process, he used professional discretion to work around this process, and prioritise work on Cathwell to ensure the Exalt's positive reputation. He had opened-up the process as matters of concern (Latour, 2004).

Once unsettled as matters of concern, the QRI process can be 'tinkered' with, exchanged, expanded, or deleted. That is, the actors that have been gathered to perform the QRI are made visible for negotiation, and to perform further partial translations to respond to a new, or unanticipated challenge. This 'tinkering' reflects findings from Styhre's (2009) and Timmermans and Berg's (1997) studies, which show how flexibility to adapt protocols is crucial to 'make things work' (Styhre, 2009, p. 387). It is this on-going, materially-mediated tinkering that, I argue, could be understood as practice-based innovating.

However, it is pertinent to question whether constantly enacting innovating practices is always helpful. If an emerging industry, or organisation, needs to succeed and grow, there needs to be some sort of stability, arguably brought about through standardising processes. In later ANT writings, it is common to read about how to recognise multiplicity, and that the state of fluidity is a positive achievement. But what about when complexity needs to be reduced? As Callon (1987, pp. 93–94) argues, part of ordering is to simplify "for the reduction of an infinitely complex world". He maintains that, "such simplifications will be maintained so long as other entities do not appear that render the world more complex by stigmatising the reality proposed by them as an impoverished betrayal". So, it becomes a key knowing-in-practice for the engineers about assessing when to simplify and when to mobilise other entities to start opening-up matters of concern to tinker with.

Flow

During my observations, I became attuned to a semblance of flows that were being maintained to balance and negotiate the four tensions presented in the previous section. I refer to flow not in a managerial sense, such as workflow management systems, but as flow of energies that denote fluidity and movement. I argue that enacting a dynamic stability sensibility required highly fluid and flexible ways of working that were attuned to maintaining this flow of energies. 'Flow' was quite a difficult phenomenon to articulate at first, but the longer I was immersed in the engineers' everyday work the more sharply I could sense it. The notion of flow implies that while there are interventions that try to direct and constrain the flow's movement, like irrigation channels, its actions cannot be fully controlled. There are many actors that can send it off-course, which need to be enrolled, cajoled, and tamed. But these can also destabilise the flow and send it in another direction altogether, like a mudslide blocking the irrigation channel and causing a flood. The notion of flow is raised in several of Law's (e.g., 2011a) essays, and is central to his argument about our response to today's global problems and disasters.

Maintaining these flows amidst non-coherence seemed to be a key knowing-in-practice for attuning to the distributed aspects of working in a volatile industry. For engineers' practices, the progress of work was vulnerable to a heterogeneous combination of natural, social, and technological flows. These flows were not singular, but many. For example, the engineers were learning how to affect and be affected by different and competing assemblages, such as multiple performances of timelines and notions of 'finished'.

Another critical knowing-in-practice seemed to be attuning to points of disruption in the everyday flow of work. The engineers, while recognising and trying to solve the problem, would patch together the flow to appear coherent, and reassure the clients that their project was still being actively managed and progressing on schedule. For example, in Chapter 6 (p. 181), I showed that the networks performing the Exalt as 'finished' were still successful, even though turbine components had to be swapped about, and only one turbine was generating by

31st March. These knowings-in-practice implied a certain agility and nimbleness to respond to situations.

Here, my findings support Sørensen’s (2009) criticism that the network imagery in Law’s (1987) heterogeneous engineering concept does not account for components of a network dropping away or swapping about. As de Laet and Mol (2000) showed, this fluidity allows objects to change shape slowly, to become mutable, and to fit the local needs of the assemblage they are enrolled in. The Exalt, as an assemblage, still managed to stay precariously stable and able to perform as an ‘object’ despite, or in fact, *because of* being composed of towers not originally intended for its construction. The fluidity, the *looseness* of the flows allowed for this flexibility and workarounds.

Law (2011a) draws on sociologist Perrow’s (2011) work concerning the architecture of vulnerability to distinguish between tightly or loosely coupled systems. In tightly coupled systems, the flows are rapid, making it very difficult to slow them down and for anyone/thing to intervene. Loosely coupled systems, on the other hand, flow much slower. It is within these looser, flexible relations, that spaces afford opportunities for intervening if things begin to go wrong or need working-around. As Fenwick and Edwards (2011, p. 726) state, paradoxically, these “precarious and sometimes incoherent assemblages, and their strategies of oscillation, juggling, and patching together across these different worlds, may be producing the most important sorts of continuity”. For example, this looseness was helpful for engineers to be able to judge what the range of allowable deviation could be to ‘work-around’ standard processes, such as the SGP.

The *sensing* of flow also raises issues of embodied and aesthetic engagement. It seemed that I was observing the engineers sensing flow through being able to see, hear, touch and be in amongst the wind farm site. For example, for Walter to appreciate the project’s progress, he wanted to travel to site, walk amongst the concrete foundations in the muddy fields on the wind farm site, take photos of spidery cables, and talk face-to-face with contractors in temporary Portakabins.

A need for aesthetic and embodied engagement was also evident in the learning strategies engineers adopted when they wanted to assess a problem they had not come across before. These included travelling to the wind farm site to experience the convergence of a theoretical modelling with visual and sensory appreciation of the turbine in the field. Engineers wanted to learn to become sensitive, and thus attuned to, the subtleties of a functioning, or non-functioning, turbine, as Andy implied when said he liked to have the "kit in front of you". This affective knowing (Gherardi, 2017b) translated the senses into an organisational concern, which allowed the engineers to attune to progress, problems and flow.

In this section, I have shown that the notion of fluidity and affective knowing were key knowings-in-practice that afforded the continuous performance of stability in volatile situations. These knowings-in-practice helped shape flow, and were themselves shaped by different flows. Attuning to flow, I therefore argue, is key characteristic of enacting a dynamic stability sensibility. Finally, the notion of flow is also useful to disrupt the image of singular, disciplinary boxes. Law (2011a, p. 13) states that, "if the flows are heterogeneous, then we need to think in ways that can handle that heterogeneity". This is addressed in the next section where I discuss interdependent knowledge practices and how these are patched together.

Interdependent knowledge practices

This section explores how enacting a dynamic stability sensibility prompted the 'patching' together of different knowledge practices. Because of my unfamiliarity of engineering education at the outset of this study, I now realise I underestimated the social, cultural and material differences between electrical, mechanical, and civil engineering. I soon appreciated the different technical knowledge practices emerging from each field and the need for these to speak to each other. As I showed throughout the analysis, engineers' work was being organised through multiple collaborative and collective efforts to dissolve the 'silo' effect and share knowledge practices and expertise. This observation follows recent engineering education literature that argues engineering practice is becoming increasingly collaborative and inter-professional (Anderson et al., 2010; Schmiede & Will-Zocholl, 2011; Vinck, 2003), and supports Styhre et al.'s (2012, p. 164) assertion that the success of creating an end-product was "based on an ability to create a collective understanding on the basis of distributed elements of knowledge". It also upholds Jensen et al.'s (2012, p. 4) claim that professionals are operating within "circuits of knowledge that exceed the boundaries of local work practices".

In Chapter 5, I introduced the notion of 'patching' to describe how these collaborative, interdependent process of project-based style of working – 'projectifcation' (Ekstedt, 2009; Midler, 1995) – were enacted as sets of local networks, coming together as a collective, distributed, yet often partial, effort. I now argue that 'patching' is a helpful concept to show how multiple knowledge practices jostle together. I also propose that enacting practices of distributed support was a key knowing-in-practice to afford this patching together.

Currently, terms such as "bridging" (Adams & Forin, 2014, p. 101) and "boundary spanning" (Johri, 2008, n.p.) appear to be prevalent in workplace learning and engineering education literature to conceptualise interdisciplinary work. I feel that these notions could be conceptualised further, to reflect the non-coherent, nonrepresentational and partial enactment of different knowledge practices jostling together. Instead of presenting these patchings as 'boundary' crossing or spanning, which create images of separation, perhaps a focus on connections here is useful. As Latour (2010b, p. 81) argues, science, technique, law, and religion do not exist as independent domains, but are instead enacted as types of relations, i.e., a connection is made legal*ly*, scientifical*ly*, religious*ly*, artistical*ly*, political*ly* or technical*ly*. I observed this relationality between knowledge practices in Andy's recollection of how he responded to the complaint of 'noise' in light of the Exalt's public image. He was not enacting purely technical engineering knowing, but instead, was patching together knowledgeable practices that had connections that were perhaps more related to public relations disciplines.

Thus, to respond to the challenges and tensions emerging from a volatile industry, it is unhelpful "to limit the inquiries to one domain only" (Latour, 2010b, p. 76), but instead realise, as Law (2004, p. 23) states, that "everything is connected and contained within everything else". Latour (2010b, p. 81) thus maintains that our attention should centre on "the modes of connections", or "modes of existence", rather than fixating on bringing together two 'separate' disciplines. This understanding is helpful to explore how patchings are enacted without attempting to impose false coherence.

How practices are patched together through different connections could be likened to the metaphor of sewing, and the different quality of threads used in Law and Mol's (1995, p. 290) notion of "patchwork". They describe the allegory of patchwork as follows:

> It's to imagine that materials and social – and stories too – are like bits of cloth that have been sewn together. It's to imagine that there are many ways of sewing. It's to imagine that there are many kinds of threads. It's to attend to the specifics of the sewing and the thread. It's to attend to the local links. And it's to remember that a heap of pieces of cloth can be turned into a whole variety of patchworks. By dint of local sewing. It's just a matter of making them.

This allegory helps depict how multiple knowledge practices could hang together, or relate, when they are performing themselves in a manifold of ways as local, partial and decentred arrangements "without the expectation of pattern as a 'whole'" (Law & Mol, 1995, p. 288).

In their study, Kaplan and Vinck (2014, p. 76) described what I would view as patching. They found that, when challenged by a new field, engineers engaged in two kinds of practices: "the first refers to the use of existing solutions coming from another domain … the second is the engagement of in-depth theoretical and strategic thinking above any established knowledge or rule-of-work". When faced with the unknown, for example, Paul mobilised material actors that they had used in previous practices (see p. 169). Practices were also being created anew, for example, changing the ordering and frequency of project team meetings, and enacting the timeline in the PCE as a boundary object to manipulate expertise from technical support and project manager engineers.

In this section, I also want to argue that distributed support is a key knowing-in-practice for achieving a 'patching' of knowledge practices. Trevelyan (2007) argues that technical coordination is often an over-looked yet prominent aspect of today's collaborative engineering practice. Although my findings support this assertion that technical coordination is a significant knowing-in-practice for engineering work, I argue that *distributed support* is also an over-looked knowing-in-practice being enacted to achieve collaborative ways of working.

Sharing technical expertise was one example of this distributed support. However, it was not a case of simply 'transferring' different knowledge from one engineer to another; sharing technical expertise was a highly embodied and material performance of support. It was enacted through infrastructuring practices (the SGP), spaces (the open-planned offices), and bodies sharing small spaces in Portakabins on the wind farm site. These materialisations of support encouraged human and non-human actors to connect, translate, and learn from each other during everyday, mundane interactions. However, as I have shown in the analysis, this was never a straightforward 'bridging' but instead a partial, over-lapping and often contested 'patching' of different knowledge practices through multiple assemblages.

In summary, I argue that enacting a dynamic stability sensibility involves the flexibility to make different 'modes of connections' between different knowledge practices (electrical, mechanical engineering, as well as sales, marketing, public relations disciplines). This understanding of patching, which generates different practices of distributed support and blurs engineers more traditional roles, helps address the tensions outlined in the first tension in RQ1: that professional knowledge can be understood as a contingent achievement sustained *by* professional practice and knowledge.

To conclude RQ2, I have shown four dimensions of a dynamic stability sensibility that can account for complexity, non-coherence and relationality, and which can tolerate the fluidity of a high-change, volatile industry. So, if I am proposing that dynamic stability is a useful sensibility for professionals to develop so that they can respond to, and negotiate, the tensions unfolding in volatile, emerging industries, how could education practices promote and support this sensibility?

Addressing Research Question 3: Pedagogical implications emerging from a 'dynamic stability' sensibility

In this section, I consider what the education practices may look like that could support a dynamic stability sensibility by addressing RQ 3, *What are the pedagogical implications of a practice-based, sociomaterial understanding of engineers' everyday practice for pre-service education and workplace settings?*

As Fenwick (2015) states, sociomaterial perspectives redirect the pedagogical focus towards the larger sociomaterial collective and away from the individual learning subject. Thus, the pedagogical implications addressed in this section acknowledge the bodies, technologies, processes and spaces that are constitutively entangled in everyday knowing and learning.

Firstly, I consider the pedagogical implications for working in loose networks and multiple flows. I then introduce Shulman's (2005a) notion of 'pedagogies of uncertainty' to discuss how education practices can be assembled to support students and professionals to work productively in an increasingly complex and uncertain world. I draw again on Ellström's (2010) notion of practice-based innovating to imply that infrastructuring processes are temporary sociomaterial enactments, which can be tinkered with to afford dynamic stability. I promote a need for education practices to foreground a critical attunement to the mediating role of objects to foreground networks of power. Finally, I propose the pedagogical cultivation of networked, relational approaches to teaching engineering disciplines, to better reflect the increasing collaborative, supportive and distributed ways of working.

Navigating loose networks and multiple flows

A characteristic of dynamic stability is working in loose networks, which affords flexibility and fluidity. In an emerging industry, it was not uncommon to be working with processes that were unfinished or not yet developed. Although working in systems that were too loosely coupled impeded competent knowing, such as Jeremy's frustration with the incompatibility of German processes, I also showed that most of the engineers seemed to flourish in the fissures that this looseness afforded them. It seemed to create spaces that promoted creativity and adaption, which were helpful for progressing Ellström's (2010) practice-based innovation. This has pedagogical implications for how practitioners could be best supported to navigate loose networks.

A second pedagogical implication concerns an appreciation of working within and through multiplicity. As I explicated in the fourth tension in RQ1, attuning to issues of in/visibility and multiplicity invites educators to consider how they might best help engineers evaluate competing and contrasting versions of reality, for example, by considering such questions as “Which version might be better to live with? Which worse? How, and for whom?” (Mol, 2013, p. 381). To work with this perspective, educators need to acknowledge the fact that presence and absence are not opposed to one another, but can exist at the same time. These questions reflect a knowing-in-practice view of knowledge, which appreciates that the answers to these questions may be highly situated, local and emergent. The concern then becomes how to support professionals to attune to and navigate issues, and effects, of multiplicity.

Thirdly, multiple ways of ordering emerged from within these multiple flows. A key knowing-in-practice emerging for the engineers appeared to be making calibrations about the allowable scope for working within this looseness. They were faced with questions such as, what constituted ‘acceptable’ practice? How far could they deviate from ‘acceptable’ practice? How tolerant was the system? At which point could they step over into unacceptable practice? Although this fluid bending of processes and standards is characteristic of how everyday activities tend to work, they are often unacknowledged practices, and, as such, mostly absent from pre-service curricula and unaccounted for in official work-place training.

Thus, educators are challenged with exploring discretionary decision-making as a situated, emergent, local and *material* performance, rather than as an individualised achievement. Here, I am not arguing that students need to be taught the specifics of workarounds, but perhaps an appreciation that they are commonly enacted in practice. This could be framed as managing the interplay between the performative and ostensive to judge when workarounds are useful, and when they may violate regulations or engender unsafe action. Following Joe and Walter’s suggestions of looking to others’ practices to assess these judgements, workplace settings could also introduce more formalised learning strategies such as structured shadowing and mentoring, which I explore in more detail in the following chapter.

Dwelling comfortably in uncertainty

In this section I consider how uncertainty, paradoxically, allows the engineers to dwell comfortably in the looseness of their practice. As maintained by Vincenti (1990), uncertainty is a key aspect of engineering, and is made more pervasive by the volatile political, economic and cultural dynamics in the wind energy industry. From a sociomaterial perspective, Fenwick and Edwards (2017, p. 16.) stress that uncertainty does not just equate to ambiguity, but acts as "an operating principle in everyday life", where "chance and emergence are always operating in the unfolding configurations, which continually open a multiplicity of possibilities".

In TurboUK, I observed that engineers often had to act assertively in uncertain situations. For example, Paul could not predict the trajectory of the Exalt turbine as it became enrolled into his everyday working yet he needed to make decisions that concerned the Exalt to keep the signature in play. I draw on a literary quote that helps show how living with uncertainty demands a productive response if one is to thrive in today's complex world. In a selected letter (Keats, 1817/1981), the English romantic poet, Keats refers to how those who can dwell in this unsettled space are adopting a 'negative capability'. Although paired with a pessimistic adjective, he meant to describe this capability in a creative and positive sense: "when man is capable of being in uncertainties" (p. 48). Embracing a 'negative capability' helps unsettle the traditional Western attempts at generating order over disorder. It invites an acceptance of a messier, contradictory sensibility to approaching the social world, where "we need to unmake our desire and expectation for security" (Law, 2004, p .9). Dovetailing with Fenwick and Edwards' (2017) understanding of uncertainty, a 'negative capability' can also act as an operating principle in everyday work, generating moments of innovating and creativity.

In addressing the need for security and certainty from an educational approach, Shulman (2005b, p. 57) states that, "learning to deal with uncertainty in the classroom models one of the most crucial aspects of professionalism, namely, the ability to make judgements under uncertainty". Such learning requires what Shulman (2005a) calls "[p]edagogies of uncertainty". 'Pedagogies of uncertainty' are not necessarily about dealing with uncertainty itself but how to work within it and embrace it; how to understand the art of inventing new ways of knowing in opaque and contingent spaces. I want to move Shulman's proposal forward by considering how 'pedagogies of uncertainty' could extend into practice. I address this in the following chapter.

Supporting practice-based innovating

In addressing RQ2, I have shown that dynamic stability sensibility approaches the notion of innovation not as a product, but as processes which are an on-going, everyday accomplishments. Again, if I asked the engineers, they would likely say, "This is not innovation!" However, I argue that this is the innovation that is enacted in a dynamic stability sensibility. Looking to Ellström's (2010) balancing of the logic of development and production is helpful to address pedagogical implications of this approach. He argues that it is within the tension and contradictions between the two logics that learning opportunities emerge. Thus, although the study of infrastructure can be considered boring and mundane (Bowker & Star, 1999), I have been left wondering whether education practices should pay more attention to the material and relational importance of innovating processes and standardising practices, which constitute infrastructuring work.

In tracing the work of the SGP, I have shown how processes were being performed in practice rather than in their ostensive form. The knowings-in-practice enacted as tinkering (Mol, 2002) and tailoring (Bowker & Star, 1999). For example, Andy took it upon himself to set up a working group to address the SGP breakdown at Gate 7. Ellström (2010, p. 34) highlights this risk-taking as a "preparedness to question, reflect on and, if necessary, transform established practices in the organization into new solutions, or ways of working". Here, the task to improve the process was not ascribed 'from above' but emerged 'from below', challenging the more traditional 'top-down model' of innovation, and requires support for risk-taking from both practitioners and employers. Fenwick (2003) also highlights the importance of employees' awareness of the learning opportunities encountered as part of the daily work and how the employees are positioned as subjectivities within networks to actively engage in these opportunities.

Ellström (2010, p. 36) argues that it is how employers "intendedly or unintendedly, shape the workplace as a learning environment [that] we are likely to affect the scope for practice-based innovations". Therefore, in workplace settings, spaces need to be provided in which practitioners can be supported to unravel existing processes, standards, protocols or ways of working as matters of concern, without fear of being reprehended for being antagonistic or challenging authority. A questioning approach to infrastructuring practices can thus highlight how specific modes of ordering may be reproducing power imbalances, unproductive or unhelpful ways of working, and inequalities. In this sense, I would argue that practice-based innovating is inextricably linked to pedagogical implications about how to critically attune to power relations, which I discuss in the next section.

Appreciating the mediating role of objects in networks of power

By emphasising the relational, precarious and recursive performance of protocols, processes and standards in practice, I have shown how the shifting role of objects can mediate power relations. This perspective raises important pedagogical implications about how engineers could appreciate that human action and intention are interwoven, but not predominant, in the unfolding of power relations. As Star and Ruhleder (1996, p. 113-4) have intimated, whilst "loose talk" of infrastructure may be harmless for everyday usage, "such talk may obscure the ambiguous nature of tools and technologies for different groups, leading to de facto standardization of a single, powerful group's agenda". Therefore, educators and managers may need to be wary of representational approaches to processes and standardising practices. If infrastructuring practices are continually taken for granted as stabilised, pre-existing entities, the relational and material process of creating power remains invisible, and, importantly from a pedagogical viewpoint, "obscures possible points and political practices for interference and change" (Edwards & Fenwick, 2015, p. 1440).

Pedagogical approaches could look to how everyday tinkering of practice-based innovation could encourage an 'interference' of infrastructuring processes, which, as Bowker, Baker, Millerand, and Ribes (2010, p. 99) propose, "involves unfolding the political, ethical, and social choices that have been made throughout its development". This leads on to considering Latour's (2004) matters of fact and matters of concern. To treat practices as matters of concerns is to treat practices as "things with a politics inherent in them" (Edwards & Fenwick, 2015, p. 1393). From an education perspective, "keeping open the controversies, or at least slowing down the processes of resolving controversies about that of which the world is made" (Edwards & Fenwick, 2015, p. 1393), could be a useful learning strategy for students, or practitioners, to question "what knowledges are circulating here, how are they being constituted and extended, what work are they performing, and what (desirable or undesirable) consequences of regulation and possibility are they producing?" (Fenwick & Edwards, 2014, p. 48).

Furthermore, appreciation of the different roles objects can perform through diverse translations in the workplace could be useful to resolve contrasting understandings of objects and their status between collaborating partners (Nicolini et al., 2012). For example, Koskinen and Makinen (2009) argue that project contract negotiators could benefit from viewing a contract as a boundary object because, "as they begin to see how they exist, a major force of leverage to assist stakeholders in coming to project contracts will be available" (p. 37). Thus, a focus on the mediating role of objects and the notion of translation could help practitioners become "sensitised to accounting for how relations that allow different parts to connect came into being" (Sørensen, 2009, p. 61).

Cultivating a patching of knowledge practices

In the previous section, I argued how interdependent practice may be more helpfully conceived as a 'patching together' of different knowledge practices, enacted through networked and relational ways of working. These knowledge practices enrol previous expertise but are also created anew within different assemblages to respond to novel or unpredictable demands. These practices included knowings-in-practice such as sharing of expertise, technical coordination and different practices of support. However, from a pedagogical perspective, the participants often felt ill prepared by formal education to perform these networked practices. For example, as with the other participants, Paul's pre-service education was in a single discipline, in his case, mechanical engineering. However, Paul acknowledged that to enact competent knowing in his job he needed to connect with other engineering disciplines that were perhaps excluded from his technical training. Thus, from a pedagogical perspective, educators may be tasked with how to cultivate and support networked ways to ‘patch together’ knowledge practices both in the workplace and in pre-service education.

In the TurboUK workplace, I noted that many of the engineers seemed to have a genuine interest in developing their professional engineering expertise to be able to respond better to the multiple tensions of the wind energy industry. In the workplace, Adams and Forin (2014) suggest that the sharing of expertise can be encouraged by “recognising the limits of your own knowledge and the need to engage with others” (p. 115), and attuning to the differences in knowledge disciplines as creating opportunities to learn. However, the workplace needs to be able to support spaces for these opportunities to emerge.

In pre-service-education, Trevelyan (2014, p. 54) argues that one of the biggest challenges for educators is to “bring together many disparate aspects from the different disciplines that offer explanatory power relevant for engineering practice”. I am not arguing for a degree course that teaches all the engineering disciplines in one programme, but for a reconsideration of what Shulman (2005b, p. 52) calls ‘signature pedagogies’, which are “types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions”. These modes of teaching are distinctive to a particular profession, and are pervasive both within university curricula and throughout the general pedagogy of the profession itself. However, the habitual and routine nature of signature pedagogies can also limit educational development: “Signature pedagogies, by forcing all kinds of learning to fit a limited range of teaching, necessarily distort learning in some manner. They persist even when they begin to lose their utility, precisely because they are habits with few countervailing forces” (Shulman, 2005b, pp. 56–57).

The particular knowings-in-practice and learning strategies that I have identified in engineering practice present a challenge to this pedagogical inertia. Fenwick and Edwards (2014, p. 47) argue that a curriculum of matter-ing could provide a basis to disrupt signature pedagogies, and “to enact and intervene, rather than to learn about and of subjects”. In such a curriculum, they contend that, “education could focus less on subject-centring and more on destabilising and decentring the certainties that have accumulated to authorise particular subjects in particular historical and regional contexts" (p. 47). Representational imageries of knowledge are thus challenged by a relational approach to understanding how knowledge has been 'black-boxed', or collapsed into matters of fact.

Chapter summary

This chapter set out to discuss the various themes and specific instances analysed in Chapters 4, 5 and 6 in relation to the three research questions that guided this study.

In addressing RQ1, I explored four tensions that I observed were of particular concern for the engineers' practice. These included balancing: commercial objectives and client needs with traditional engineering concerns such as health and safety; standardising practices with innovating practices; acceptable practice with allowable deviation; and visibility with invisibility.

Exploring RQ2, I introduced the concept of dynamic stability sensibility and explored what this sensibility looks like in practice. I presented four dimensions of dynamic stability that included: networks of power, opaque spaces and the mediating role of objects; practice-based innovating; flow; and interdependent knowledge practices.

Focusing on RQ3, I considered the pedagogical implications of a practice-based, sociomaterial understanding of engineers' everyday work, and what education practices may look like that could support a dynamic stability sensibility. These included working in loose networks and multiple flows; dwelling comfortably in uncertainty; supporting practice-based innovating, appreciating the mediating role of objects to foreground networks of power; and cultivating a patching of knowledge practices.

I draw on these discussions to suggest that perhaps new ways of approaching traditional engineering education practices should be considered, which better reflect the networked, relational ways of working in complex, volatile and emerging industries. I discuss some possible suggestions and implications to this argument in the next chapter.

Chapter 8: Key insights, recommendations and reflections

In Latour's (2005) sociology of associations (ANT), he urges modesty. Therefore, in this thesis I have not been "after grandeur" (p. 136), but have aimed to "add text … to a given state of affairs" (p. 149). In this chapter, I summarise what text I have added to the affairs of education research. I begin by restating the three research questions that guided this study, and I provide a summary of how this thesis unfolded to address these questions. I then present three key insights that emerged from this investigation. Based on these insights, I have provided recommendations for practice, which are split into two strands: pre-service education, and workplace settings. I then suggest three possibilities for further research that have emerged from this study. I reflect on the challenges of conducting a sociomaterially-informed methodology, and offer guidance for future researchers. I close with thoughts about how future ANT work may offer a crucial methodological and theoretical approach to address pressing questions of professional practice and education related to complex global issues.

Restating the research problem

In Chapter 1, I showed how recent scholarship and policy reports have highlighted that education practices are falling short in adequately preparing professionals, specifically engineers, for work in volatile, high-change emerging industries. I argued that three concerns must be considered concurrently to address this issue: the shifting intellectual landscape of engineering education; the wider sociological issues of changing professional work; and emerging approaches to reconceptualising workplace learning research.

I worked with three propositions that emerged from this literature. Firstly, I understood knowing as emergent, situated, contested and materially-mediated, rather than as 'knowledge'; a rational, cognitive entity to be 'acquired'. This led me to work with Gherardi's (2001) notion of 'knowing-in-practice', which links knowing with doing. In pluralising this phrase, I extended this concept to reflect the multiplicity of engineers' knowing-in-practice, by referring to specific and particular ‘knowing*s*-in-practice’. Secondly, my focus of inquiry shifted from the individual to practice, where practice was understood as “embodied, materially mediated arrays of human activity centrally organized around shared practical understanding” (Schatzki, 2001, p. 2). And thirdly, I followed a sociomaterial perspective (Fenwick & Edwards, 2010), emphasising a relational and performative understanding of knowing that foregrounds the role of materiality. Knowing is thus understood as emerging through different relations connecting in a sociomaterial performance.

I have used the term ‘learning strategies’ to highlight learning as a practical accomplishment that is performed in action, and is implicated within knowing-in-practice. In this sense, I recognise learning as the unanticipated and unpredictable refinement and emergence of local knowledgeable practices in order to enact competent knowing. However, in trying to account for the ‘learning’ in this study, it is fair to say that I have found it very difficult to pin down and define the notion of ‘learning’. From a methodological angle, it was very hard to identify when engineers were making movements from the familiar to the unfamiliar. Similarly, I was not directly asking the participants to tell me how or when they ‘learnt’. I was observing their practices, and therefore could only witness when they struggled, or told me about a problem and how they then resolved it. Thus, I focus on engineers’ *knowings-in-practice,* rather than trying to identify exact moments of learning.

In Chapter 2, I teased apart the concept of knowings-in-practice further, highlighting three aspects that I found particularly useful to elucidate knowings-in-practice in my study. These included embodied and aesthetic understanding, collective know-how, and on-going, materially mediated action. I then presented ANT as a complementary theoretical approach, which foregrounded the role of materiality. ANT offered theoretical concepts that helped me trace *how* knowings-in-practice were being performed, and what effects they produced. In particular, I drew on the following theoretical concepts: translation, obligatory passage point, network, assemblage, performativity, heterogeneous engineering, multiplicity, fluid objects, boundary objects and matters of fact and matters of concern. Using these theoretical resources, I showed that, if researchers start to consider engineering work to include not only human engineers as actors, but also processes, open-planned offices, contract signature pages, timelines, sound, technical components, analysis software, and government policies, then a rich field of social inquiry emerges in new and exciting ways.

The theoretical underpinnings of knowing-in-practice and ANT thus guided my study, and framed how I addressed the following three research questions:

1. What tensions are professional engineers negotiating as they work in a volatile, high-change, emerging industry?
2. What knowings-in-practices and learning strategies are evoked by these tensions?
3. What are the pedagogical implications of a practice-based, sociomaterial understanding of engineers' everyday practice for pre-service education and workplace settings?

Methodologically, I conducted an ethnographic study over six months, in which I followed and observed 13 engineers and the objects of their practices in TurboUK, a wind turbine provider and installation organisation, to gather data. This data included a daily report, relational maps drawn by the participants, semi-structured interview transcripts, and photographs taken by both the participants and myself. As I was interested in a networked, relational perspective of knowing, I worked with these materials to trace the relations between the engineers and the objects of their practices during their everyday work activities. Following a sociomaterial understanding of what constituted an 'object', I was mindful that I approached these 'objects' as complex gatherings that were being continuously performed in the moment, rather than as stable entities.

In the workplace, I looked for occasions that created palpable energies, where tension was rife and their presence appeared impossible to ignore. I focused on instances of innovation, distance and breakdowns, which foregrounded the work that the mediators were doing to perform an entity. I was drawn to three activities that were *doing* work**:** obtaining a signature on a contract, the unfolding of a specific organising process, and implementing a new technology. Following the work mobilised by these three activities acted as "entry points for describing complex assemblages of objects, people, and knowledges" (Fenwick & Landri, 2012, p. 4). I looked to Latour's (2005) endorsement of description, and Adams and Thompson's (2016) recommendation of posthuman anecdotes, as analytical heuristics to present detailed analyses of these three activities in Chapters 4, 5 and 6. Chapter 7 then discussed the implications of these analyses in terms of existing literature and broader issues of practice and education. In the following sections, I offer syntheses of these discussions, and apply them to suggest recommendations for practice and further research.

Key insights

In this section, I present three key insights that have emerged from this study, which have implications for education practices.

'Dynamic stability' sensibility: A performative understanding of infrastructuring practices

In this study, I have proposed the notion of 'dynamic stability', which has been helpful for highlighting a performative understanding of engineers' practice in a volatile industry. I have introduced dynamic stability as a sensibility that involves enacting particular knowings-in-practice, which include: practice-based innovating and tinkering; attuning to different flows through *fluid* heterogeneous engineering and affective knowing; and patching together different 'modes of connections' in collaborative ways of working. Tracing the performance of these knowings-in-practice, I argue, is key to understanding in more detail how engineers' practices tolerate a high-change, volatile industry.

This is an important insight to think about how infrastructure is conceptualised, or as I have termed in this thesis, infrastructuring practices. Instead of focusing on a tight, or rigid infrastructure imposed 'from above', I have shown that infrastructuring practices are performed as sociomaterial processes, involving different assemblages of various human and non-human actors gathering together in working relations and networks to perform work. From this perspective, I observed how engineers' practices seem to thrive in organising processes that create opaque, or slack, spaces, which afford a looseness, fluidity and flexibility for contingencies, tensions and power relations to be negotiated. I have shown that in these spaces, workarounds (Pollock, 2005), or small subversions (Suchman, 2000), to ostensive rules or processes are continually performed to get the work done against tight deadlines, shifting policies and rivals' competing products.

Collaborative ways of working, such as projectifcation (Ekstedt, 2009), also appear to be crucial infrastructuring practices, mobilising different practices of support and expertise. However, as processes and standardised practices that delineate these ways of working are still developing at TurboUK, a certain looseness to adapt these processes is necessary to respond to unpredictable and uncertain events. This looseness affords practice-based innovating to unfold (Ellström, 2010). This practice of innovating is not focused on creating new products, or sourcing profit, but is concerned with modest innovating in everyday work (Suchman & Bishop, 2000): bit by bit, objects or processes are 'tinkered' with to meet the demands of a particular situation, at a specific time and place. I have looked to Knorr-Cetina (1979), Timmermans and Berg (1997), and Styhre's (2009) work on 'tinkering' to denote a disruptive, persistent action performed incrementally and gradually, without an overarching plan, to fluidly adapt an assemblage and carve out solutions that work locally.

From a pedagogical perspective, I have shown that a sociomaterial analysis can make visible those aspects of infrastructuring that function pedagogically, such as tinkering and practice-based innovating. I propose that education practices could attune to these knowings-in-practices, which I have termed a dynamic stability sensibility, to invite new questions around working in uncertain, opaque and unstable spaces, rather than striving for certainty and order. Furthermore, infrastructuring practices could be foregrounded as matters of concern for education practices, for a more critical appreciation of the performative, relational effects of organising processes.

Negotiating tensions as sociomaterial processes

Another key insight that emerges highlights that the multiple tensions that engineers are facing in their everyday work were negotiated through sociomaterial processes, rather than just individual, human-centric action. A focus on the many heterogeneous actors circulating in the various assemblages mobilised in engineers' everyday work helped shift the study's emphasis from concentrating on the individual, to an emphasis on materially-mediated practices. In Chapter 1, and in examining RQ1 in Chapter 7, I have shown some of the tensions prevalent in engineers' work. In this section, I highlight the tension between enacting acceptable practice and judging the allowable range of deviation as an example of how negotiating tensions could be understood as a sociomaterial process.

In Chapter 5, I showed how Walter, a project manager engineer, subverted a new quality assurance processes as he wanted to arrange his own transport plans directly with the company, and maintain his close relationship with them. Making the decision that this was 'acceptable practice' and was within the limits of deviation from the codified, or ostensive, rules could be understood as a discretionary act (Evetts, 2002). However, I argue that making a discretionary decision-making to enact acceptable practice is a sociomaterial performance.

The judgement about making this decision appeared to be a calibration between multiple factors. Firstly, the engineers had their own desire to have autonomy to, "do their work as they see fit on the basis of their own sense of knowing how to do it" (Evetts, 2002, p. 342) (for example, when Walter knew it would take less time to go the transport company directly). Secondly, the decision was shaped by the available social and material conditions (Walter could pick up the phone and call the transport company; the process had not been delegated to a dropdown menu on a database, which may have restricted Walters' actions). Thirdly, the collective know-how influenced what constituted 'acceptable practice' in that particular space and time (informally sanctioned by his line manager even though it deviated from the process because it helped maintain their relationship with the transport company). Therefore, negotiating tensions, and enacting competent knowing, can be understood as sociomaterial processes, situated and distributed between various social and material actors.

From a pedagogical approach, understanding that humans are not as in control of decision-making as they may think they are is an interesting and disrupting perspective of how students and practitioners may be supported to approach the negotiation of tensions.

'Patching': Disrupting representational understandings of knowledge

The final insight I present disrupts representational understandings of knowledge by reconsidering engineers' work as collective 'patchings' of knowledge practices. In Chapter 1, I highlighted that to respond to challenges in today's professional work requires diverse expertise and resources which one actor alone cannot offer. Collaborative, interdependent ways of working are increasingly introduced to organise, and gather together, these different knowledge practices. However, I argue that current metaphors used to imply the coming together of different bodies of knowledge or expertise as 'spanning' or 'bridging' belies the partial, incoherent and on-going performance of how knowing is enacted in practice. Instead, I have shown that it may be more helpful to think of bodies of knowledge as precarious assemblages that could be 'patched' together through differing strengths of connections.

As discussed in detail in Chapter 7, page 213, I used the term 'patching' to show how multiple knowledge practices jostle together in multiple and partial ways to achieve this collective expertise and know-how. For example, the assemblages that Andy was enrolled in to manage the noise complaints of the Exalt necessitated knowledge from fields such as public relations, local government policy, marine science, as well as technical understandings of sound propagation. Firstly, this example also shows that traditional engineering education practices, which focus on teaching mathematical and science-based knowledge, may be failing to acknowledge other important disciplines that are enrolled in engineers' practices. Secondly, by focusing on the actor (sound levels), rather than distinct disciplines that needed to be 'bridged' or 'spanned' together, the notion of 'patching' helps shift the focus from single, bounded and stable knowledge disciplines, to an interdependent, but patchy, understanding of engineers' knowings-in-practice.

Furthermore, an understanding of engineers' knowings-in-practice as being embodied, situated, contested and materially-mediated, rather than as fixed and stable, invites other knowings to be considered as equally important as disciplinary knowledge. I am not arguing that engineers forego a foundational, technical understanding of engineering subject matter, such as the technical workings of turbine engines. I am arguing that education practices generally do not capture the aesthetic and tacit dimensions of the operating turbine, which need to be sensed in order to better understand problems, such as dealing with the 'noise' complaint on the Cathwell project. I showed how important it was for the engineers' to be enrolled in different assemblages, such as the *Exalt-as-physically-present* assemblage on site, rather than just in the office in the *Exalt-as imagined-possibility* assemblage. On the wind farm site, the engineers could *sense* progress, and talk face-to-face with clients and contractors to reassure them of problems with delivery schedules. These affective knowings were key for enacting competent knowing.

From a pedagogical perspective, considering 'patching' as a new way of thinking about how different disciplinary knowledges circulate in practice, over-lap and jostle together, can start to disrupt the inertia of signature pedagogies (Shulman, 2005b), and invites different understandings of knowing to be considered in education practices, for example, affective knowing.

Possibilities for further research

In this section I highlight three areas of further research that have emerged from this study. Firstly, it would be interesting to explore how the engineers' practices have changed in the last year, due to a dramatic political U-turn in renewable energy policy. In the case of TurboUK, political and economic networks have destabilised the continuation of wind turbine technologies. Since writing my findings, the current government announced their controversial decision for an early closure of the onshore wind subsidy scheme. As of 2016, wind farm projects were no longer eligible for ROCs (as discussed in Chapter 6)[32].

[32] A House of Commons briefing paper cited issues of escalating costs, as well as acknowledging the Conservative Party Manifesto's 2015 pledge to "halt the spread of onshore wind farms" due to the failure to win public support (p. 8).

This change in political and financial support is likely to have a marked effect on the pace and demands of engineers' everyday work, as they enter a period of political instability, job insecurity, and a pressing need for innovation and improvisation. Collecting further data to explore what knowings-in-practice have emerged, or changed, and what new learning strategies are enacted, would be a fruitful contribution to research on professional practice in volatile emerging (and declining) industries.

Secondly, I was struck by how the engineers' enjoyment and desire to be on the wind farm site – feeling, sensing, hearing the effects of the turbine – created learning opportunities through embodied and aesthetic engagement. I sensed their excitement when they 'won' contracts, and their pride in the completed wind farms. In several recent papers, scholars have raised questions about affect and emotion as subjectivities in sociomateriality (Gherardi, 2017b; Müller & Schurr, 2016).

Gherardi (2017b) speculates on how to study affect in practice-based studies without reducing it to representations, and explored "what the turn to practice and the turn to affect have in common" (p. 210). She positions affect as a dynamic process enacted through relations between different entities. She cites Reckwitz (2017), who frames affect as "an ingredient of practice, as the property of the specific attunement or mood of the respective practice … and underlines the role of artefacts as affect generators" (Gherardi, 2017b, p. 210). Thus, I am inspired to investigate further how practice and ANT-inspired theory could embrace a greater sensitivity to the role of affect in sociomaterial relations. Specifically, I would explore how enactments of pride and attachment contribute to the negotiation of tensions in professionals' everyday work.

Finally, I am also keen to feed back my findings to HE universities. I am interested in researching how a dynamic stability sensibility could be incorporated into curriculum design and what this may look like. One way could be through piloting a work-placement based on ethnographic methods and a sociomaterial, practice-based sensibility. For students who opt for the increasingly popular work placement during their degree programme, they could be introduced to ethnographic research methods, and Hager et al.'s (2012) five principles of practice theory "to attune to the world, to see and hear and feel and taste it" (Mol, 2002, p. 262).

Perhaps designed as a reflective assessment exercise, students could critically investigate the practices of the organisation they were placed with, for example, through Nicolini's (2017) suggestion of structured shadowing. The focus therefore would be less about the actual technologies and specific projects that they were involved with, and more about how they navigated the networks and the tensions that the pace of work necessitated. This refocuses learning on attuning to the complexities and tensions of professional practice, rather than on skill acquisition. This pilot could be conducted as a design-based research study (Brown, 1992), where the intention is to create an intervention, introduce it, then study what emerges. Then the work-placement could be redesigned and reintroduced, accounting for any initial concerns or issues, and mapping again what emerges. Design-based research is one method that acknowledges the mutual dependency between work practice and education practice (Sandoval & Bell, 2004).

Recommendations for education practices

In the following two passages, I propose several ways education practices could be assembled, which take into account some of the findings from my thesis. First, I offer recommendations for how pre-service education could better prepare students, and secondly, I propose suggestions for how workplace settings could support practitioners already in work in emerging industries.

Recommendations for pre-service education

As Trevelyan (2014) points out, there appears to be a lack of understanding about engineering practice in formal education. I argue that this ethnographic study has provided detailed insights into what engineers do every day to get their work done in an emerging industry. This helps address the question posed to me on page 29, "How do we design a course for students entering professions in the renewable energy sector?" However, conducting ethnographic studies is a costly endeavour, both in time, goodwill, and resource. In this section, I offer suggestions for pre-service education practices that have emerged from ethnographic methodologies, but do not necessitate students undertaking a 6-month study in the workplace.

It may be beneficial for students to understand that to practice as a professional in today's world is to continuously negotiate, and be negotiated by, multiple tensions. In being made aware that there are multifarious aspects and responses to these tensions, and that these involve not only human but non-human actors, students may be better prepared to direct their actions with more confidence. Therefore, I recommend students be presented with real-life case studies of complex situations or problems which involve multiple stakeholders. Educators can encourage discussions of possible methods that students could engage in, which maintain the 'flow' of their work, engage in problem-solving, and, at the same time, support the students to recognise and respond to emerging ethical issues.

Educators could consider teaching methods that invite students to critically question why and how potential issues in the workplace could be too hastily constructed as 'matters of fact'. To do so, I propose that educators could again use case studies or exemplars to examine a particular workplace issue, process or object, to allow the students to explore the sorts of relations between actors that are gathered together to allow the assemblage to perform in the way that it does. As a resource to help guide this questioning and exploration, they could be introduced to Hager et al.'s (2012) five principles of practice theory that I worked through in Chapter 5.

I also propose that students could read researchers' accounts of engineers' or other professionals' practice to better understand the more mundane, taken-for-granted or clandestine activities that are often left out of formal reports. For example, I found the most useful resource that enlightened me to how I could conduct a practice-based study was not by reading a step-by-step, how-to-guide, but by reading Law's (1994) account of his ethnographic experience at Daresbury Laboratories. Law's written reflections showed his emotional struggles, the political challenges, and the problems of accessing a site and generating trust, which highlighted the less visible dimensions of research methods. Thus, ethnographic texts could be introduced as a learning resource in the classroom to reflect this 'invisible work'.

In fact, Latour's book, *La fabrique du droit: Une ethnographie du Conseil d'Etat* (2002) – an ethnographic account of judges' work at the French supreme court – is used by lawyers to teach administrative law classes. In 2011 (Landri & Latour, pp. 62–63), Latour spoke to Landri about the use of his book:

> It was completely unexpected. I like that usage of my book, because it is a very classical definition of ethnography … the effect was that thousands of people who teach administrative law in France could discover how the law they teach is produced … the only things they had before Conseil d'Etat were the results, the decisions. They did not know how they work.

Ethnographic texts such as this one offer their reader a performative understanding of practice, rather one that is ostensive and representative. Engaging in ethnographic research can highlight unexpected relations between heterogeneous actors. This can encourage students to conceive of engineering work as a 'patching' together of multiple knowings-in-practice, rather than stepping into work assuming that engineering work demands will only be based on purely scientific disciplines.

With regards curriculum and course design, I suggest that a move towards interdisciplinary programmes could speak to the notion of 'patching'. Perhaps new fields of study are called for, such as mechatronics,[33] as suggested by Schmiede and Will-Zocholl (2011), which acknowledge a networked approach to engineering. In recognising the points of affinity between elements of electronic, mechanical and software engineering knowledge disciplines, educators have created a programme that better reflects the gathering of different expertise needed in today's engineering industries.

Recommendations for workplace settings

Educational practices in workplace settings take many forms and are mobilised and developed by a variety of actors, including: professional associations, HR

[33] Mechatronics is an academic course that combines elements of electronic, mechanical and software engineering education.

departments, the collective professionals, as well as HE, continuing education, and external-provider training courses. I now consider the implications of these key insights for those concerned with workplace learning.

This study has led me to ask whether practitioners could be encouraged to attune to a dynamic stability sensibility in their everyday work. For example, if practitioners were more sensitised to the ‘things’ in their practice and the different roles they can perform, how would that better facilitate their knowings-in-practice? The purposeful role of educators in this task could be to create such opportunities that ‘activate’ crucial mediators as pedagogical devices to encourage learning opportunities. I have several suggestions for how this could be accomplished.

Practitioners could be encouraged to question existing practices, as Latour (2005) advises, by making the familiar unfamiliar. Agitating the black-boxed signing process of the contract into matters of concern could be one example of this technique. It could create openings for more critical exploration and attunement, particularly around the politics and ethics of the entities that have been folded into this process.

Attuning to breakdowns in everyday activities presents learning opportunities because it is during these moments where the mediating role of objects becomes foregrounded (Latour, 2005). When technology back-talks, as in Fay’s experience of ordering turbine components on a database, or does not act as planned, as with the Exalt’s ‘noisy’ fan, rather than trying to find a solution and close down these issues, these moments could be viewed as on-going controversies, or matters of concern (Latour, 2004). These controversies could provide an opportunity for engineers to ask new questions, experience unfamiliar dynamics as well as highlighting different tensions to consider for future work.

Supportive spaces need to be established to foster the exploration of these breakdowns. Education practices could look to developing language and strategies for holding open the controversies. However, I recognise that this is a challenging mandate as the current tendency as a society is to close uncertain spaces and resolve controversies as quickly as possible to avoid discomfort, vagueness and the mess of the unknown.

The informal mentoring mentioned by Walter and Joe in Chapter 5 (p. 160) could be made more visible so that new employees can engage in peer-to-peer support. Nicolini (2017) has proposed structured shadowing as a pedagogical approach that builds on sensorial awareness and focuses on arresting moments in everyday work (similar to Latour's occasions of breakdowns). Structured shadowing mirrors some aspects of ethnographic methodologies, such as making visible complex, taken-for-granted work practices. Thus, performative (in comparison with ostensive) accounts of work, which are often left out of official job descriptions, or standardised work processes, are uncovered (Vinck, 2011). Importantly, Nicolini (2017) suggests that, unlike shadowing, *structured* shadowing needs to be facilitated through management (by a course leader, if in HE, or by a manager if in the workplace), modelled (through exemplars) and supported (through reflective activities).

Finally, education practices could be assembled in ways that acknowledge and support affective knowing. These include quite simple recommendations, such as an emphasis on travelling to wind farm sites to conduct site walks to see, feel, and touch technologies, and to sense the flow of work.

Generating an altogether different landscape: Reflections on a sociomaterial-inspired methodology and guidance for future researchers

> The job before us is no longer to go to different places in the same country - less crowded sites, less trodden paths – but to generate an altogether different landscape so we can travel through it.
>
> Latour, 2005, p. 165

In adopting an ANT approach to this study, I was working with a theoretical sensibility that had, ontologically, flipped all my previous learning on its head. My foundational training in psychology kept bringing my thinking back to that of knowing and learning as a human-centred, cognitive acquisition. As Latour (2005) implies in the above quote, I had to not just shift this thinking into a slightly different direction, I needed to embrace a whole new way of looking at the world. I must do as Edwards (2012, p. 525) advised, and “unlearn certain ingrained habits of representation in order to enact theory differently”: I had to flatten the social, focus on the local, and reject things as having an *a priori* existence.

In this section, I reflect on how I tried to generate an altogether different landscape for myself that embraced a performative and relational ontology, and a methodology that considered non-humans as important to the nature of inquiry as humans. I did this through adjusting my language and playing with different terms, experimenting with how I could ‘interview objects’ in an ethnographic methodology, and reflecting on the performativity of sociomaterial methods.

Reshuffling vocabularies

To become fluent in thinking and speaking a performative ontology, I had to learn a new language that challenged the vocabularies of my psychology-based writing habits. I needed one that was accordant with practice-based studies (Nicolini et al., 2003). Appropriating verbs instead of nouns helped steer the focus of inquiry away from representational understandings of knowledge and towards a networked description of the engineers’ knowings-in-practice. Using the present continuous tense also helped portray the sense of on-going and unfolding action, demonstrated in the shift from ‘knowledge’ to ‘knowing’, ‘infrastructure’ to ‘infrastructuring’, and ’innovation’ to ‘innovating’.

I had to be conscious of the metaphors that I was using so that I did not trip myself up and indirectly claim a social explanation that reinforced a representational or categorical understanding of knowing (Scoles, 2017b). I found that relational, active language helped me to map the complex and reflexive accounts of my ethnographic experience. I consciously chose specific verbs to describe my experiences as well as my analysis, such as ‘connect’, ‘perform’, ‘align’ and ‘mediate’. I also looked to notions of trustworthiness rather than using the positivist vocabularies of ‘reliability’ and ‘validity’ to discuss the rigour of my methodological strategy.

Interviewing objects in an ethnographic methodology

In mobilising an 'ethnography of objects' (e.g., Bruni, 2005; Mewes & Sørensen, 2017), the participating engineers were not considered the only active characters in this study. Non-human actors, such as the signature, the Exalt turbine, and the Stage Gate Process, also played important roles in how knowing was enacted. While I wanted to start the ethnography in the midst of both things and humans, traditional ethnographic methods often start with what humans do and say, for example, via interviews. However, along with interviews, I had gathered reams of observation notes, photographs and the relational maps. This helped bring the role of materials to the fore, allowing me to extend my understanding of the human and non-human, and the assemblages they performed. The extended period of time at TurboUK allowed me to map these along a trajectory of action to form a more complex, albeit perpetually partial, account of the engineers' knowings-in-practice. I now reflect on how the visual and creative exercises that I designed to complement the three semi-structured interviews helped me to 'interview the object'.

I found that the dialogue emerging from the act of drawing the relational map was perhaps more helpful than reviewing the completed map. A few participants ran out of time in the interview and requested that they take the map with them to complete later. Although they returned the maps thoroughly and thoughtfully compiled, I had lost the richness that the accompanying dialogue about the differing strengths of the various connections between people and objects. As Latour (2005) argues, visual representations "have the drawback of not capturing movements and of being visually poor" (p. 133). This was one of the issues I had with Williams and Figueiredo (2014) model of heterogeneous engineering (see p. 56). Therefore, the value of the relational map was to act as a prompt during the interview to surface not only the objects of the engineers' practice but also how their relationships with these objects were performed to accomplish their work. Furthermore, if I were to repeat this exercise, it would be interesting to ask the participants to put an object in the middle of the map, rather than themselves. This would be a useful strategy to adopt to 'interview the object'.

As I noted in Chapter 4, the participants found it hard to recall the micro-details of their practice during the ‘interview to the double’. In later interviews, I decided to ask the participants to focus on a specific activity rather than a whole day, such as conducting a meeting on the wind farm site. As they were asked to recall their work for a shorter time, the task seemed to work better. Although not as successful as I had hoped, researchers may find it a useful method for encouraging participants to verbalise activities and practices that they may take for granted when simply asked to describe their work routines.

The photo-elicitation task emerged as the most enriching activity to ‘interview the object’. The participants visibly enjoyed the novelty and challenge of thinking about what photographs to take. The photographs on the laptop and camera phones on the table provided a third party in the interview room, diluting the strain of one-to-one interviewing. The collaborative nature invited both of us to discuss our own perceptions and interpretations of the photos, following Pink’s (2007) view of photo elicitation as a meaning-making exercise. This was important from an ANT perspective because, epistemologically, I was interested in understanding the actors’ reality and not what I was imposing on them as the researcher: “you have to grant them back the ability to make up their own theories of what the social is made of” (Latour, 2005, p. 11). Furthermore, the participants started to understand what I meant by ‘non-humans’; we began to negotiate a shared vocabulary that allowed us to discuss their relationship with ‘objects’ and how they could affect the way they worked.

However, conducting interviews with photographic aids also presented some unanticipated challenges. Some participants found the act of taking photographs embarrassing, while others were not confident that they had taken the ‘right’ photos or ‘interesting enough’ photos, and, consequently, apologised profusely throughout the interview – “I’m afraid my pictures aren’t that exciting” (Lewis). Many participants struggled to see an object as anything more than a concrete artefact (i.e., a laptop or a phone). The idea that an object could also be more abstract, such as text, ideas, or spaces, did not seem to occur to many participants, even though I explained this in the prompt. Whether my explanations were faulty or the participants’ disciplinary training caused them to treat objects in particular ways, the question of what is understood to be an object is important to consider when researching participants' interactions with materiality.

Overall, these three exercises were useful additions to the research process, as they "helped prompt concrete discussions of professional 'knowing' with these engineers, moving beyond abstractions and mentalist orientations of knowing to actually describe specific instances of how knowing emerges in their practice – while practice emerges in their knowing" (Fenwick et al., 2015, p. 150). Such exercises could also be useful to help pre-service students become more aware of the influence that materials exercise on their activity.

Following, and losing, the actors

I found it exceptionally difficult in my observations to flatten everything in order to be true to the concept that everything is local. I found that the methodological strategy I had chosen to achieve this, Latour's (2005, p. 12) directive "to follow the actors", was an impossible feat. For example, sometimes the actor that I choose to follow did not cooperate: it becomes marginalised outside the network, or lay dormant for stretches at a time.

Furthermore, Latour (2005, p. 77) reminds the reader that those adhering to the directive tend to let common sense prevail: "Yet sociologists of the social are not fools. They have good reason to hesitate before following the social fluid wherever it leads them." For example, engineers' work disappeared into screens as it was translated into emails, it travelled to the participants' homes as documents on a laptop to be updated in front of the evening's television, and it journeyed to site as a project file on the train. When I realised how difficult following the actor would be, I sculpted my methodological toolkit to help account for some of the spaces and times I could not trail the key actors.

However, this challenge also raised important questions about why certain actors were hard to follow. Firstly, my research practices were reflecting the partial connectivity that is inherent to a sociomaterial perspective. I needed to accept that objects were messy, slippery and non-coherent, as well as purporting that the participants found them so. Secondly, the missing materials were powerful in their (manifest) absence. Their invisibility needed to be accounted for. So, the questions then became, what was being made opaque or invisible? What effect did this have on the engineers' practice? Thus, this realisation that actors become backgrounded, inactive, or folded into other actors became a key focus of my analysis.

Performativity

As discussed in Chapter 4, critical reflection on the researcher's positioning is key when gathering materials. Fenwick et al. (2011, p. 182) point out a "continuing dilemma" in this practice-based, ethnographic kinds of work, which "is the researcher's own implication in the enactment of the different reals. What is being enacted and represented as multiple ontologies still emanates from a knowledge-making authority". The methods I chose to gather materials performed certain realities that positioned actors in specific ways, foregrounding some and backgrounding others. Although I strove to consider non-human actors, I still tended to foreground the engineer as a key actor. While this is pertinent as it was the *engineers*' education practices that I was concerned within in this study, this preference echoes an oft-cited criticism in ANT studies that it is frequently the engineers, strategists or innovators who are positioned as the system-builders (e.g., Law, 1994), and that "they are celebrated as heroes" (Mol, 2010, p. 255). However, Mol (2010) goes on to point out that the heroes only appear so strong and powerful 'because the activity of lots of others is attributed to them' (p. 255). She refers to Latour's (1988) study of Louis Pasteur as an example of this.

I noticed that in Law's (1987) original case study, in which he proposes the notion of heterogeneous engineering, he also refers to the early Portuguese navigator (Henry) as a 'heterogeneous engineer', as if they were "standing at the heart of his or her network" (p. 132). Law (1987) acknowledges that he positions Henry as a cause, and the navigation as an effect, to simplify his analysis. Nonetheless, Law (2002) argues that social researchers must "avoid the flattening effect of imaging that there is on the one hand a great designer, a heterogeneous engineer, and on the other a set of materially heterogeneous bits and pieces … to combine them at a privileged place, that of the designer" (p. 136). He calls these tendencies "modernist versions of heterogeneous engineering" (p. 137), which fail to account for the complexities of heterogeneity. Admittedly, I struggled not to fall into this modernist trap and found it challenging not to place the engineer at the centre of the network and just ‘add objects’. For example, in describing the distributed alignment of the material constituents of the contract to prepare for signing, it was Paul who I foregrounded as the obligatory passage point (recall the infinity symbol in Chapter 4, Figure 15).

The rewarding agony of ethnography: A personal reflection

There exists an on-going debate as to the value ethnography can bring to scholarship. Watson (2011) argues that “it has too much potential to be confined to the ghettos of specialist “qualitative research” journals or to a series of heavily priced hardback monographs that few (including many librarians) can afford to buy” (p. 214). However, Van Maanen (2011) disagrees, attesting that not everyone should practice ethnography. It is labour-intensive, a lengthy duration, focuses on the particular rather than broader patterns, and it requires the goodwill and cooperation of participants. This is appropriate for some research questions and resources, but not all.

For me, I am drawn to ethnographic methods as they suit my inquisitive, social character. I am not daunted by meeting new people and enjoy the challenge of negotiating a working partnership based on goodwill. I was delighted that this doctoral experience provided me with the time and space to engage in an ethnographic study that I felt spanned a substantial period. Yet I felt I learnt first-hand the rewarding agony of ethnography. The emotional cost of going in to the office every day feeling like an outsider and expending vast amounts of energy trying to blend in as an insider was heavy.

Furthermore, I was acutely aware that the success of my thesis at this point was in the hands of others’ generosity. At the outset, I had no idea who would volunteer, how many would drop out, and how much data I would gather. After my initial fear that I would not enrol enough participants and collect sufficient data, by the end of my stay I was relieved beyond measure that it had been a success: I had data! Ironically, I had *too* much data. It was overwhelming. I thought I had done the ‘hard part’. Transcribing and then analysing over 30 interviews, six months of observations and research diary entries, took nearly another six months. I found myself exhausted, faced with this surfeit of raw data, on top of coming out of an anxiety-provoking six months in the field. Frustratingly, very few studies seemed to discuss how to conduct an ANT analysis, and I had to look carefully for nuggets of analysis advice in Latour's (2005) writing – it was not spelt out to the reader. Disheartened, I felt my focus and direction had become untethered.

Consequently, I took a break. I needed it for my health. I literally moved my PhD journals and raw data into the attic for six months. On reflection, I wish I had had the foresight to schedule in a purposeful break. The benefit of distance from such an intense period would have allowed me to take control of the situation, rather than the situation take control of me. Yet I was constrained by the timeframe of my doctoral study so taking a planned break to reenergise after my data collection was not an orthodox approach. I eventually came back to my data recuperated, refreshed and ready to approach the analysis with excitement rather than exhaustion. I slowed my pace again, taking my time to familiarise myself with the data and accepting that the analysis was going to be as slow a process as the material-gathering itself. I took the time to make sure I did not reach too quickly to matters of fact or representation.

Would I do an ethnographic study again? In a heartbeat. But before committing, I would reflect on the stories I have emerged with from this study. I would also look more closely at the scale of my research questions. Some interesting advice on scalable research comes from Bowker et al. (2010). They question whether teams of 15–20 researchers, rather than one or two, would be more suitable to studying complex and dynamic materialisations, such as infrastructures: "we need as much span in our research teams as there is in the phenomena we are studying" (p. 113). As a lone researcher, and with the desire to flatten as many networks as possible to be true to the local, I think I was, on reflection, over-ambitious with the resources I had available. Yet, because of my zealous approach, I am now privy to a plethora of data that will inform my ideas for further research.

Closing remarks: Seeking a "fully colorized version of ANT"

When studying a networked, fluid and complex world, "the guarantees, the gold standards, proposed for and by methods, will no longer suffice" (Law, 2004, p. 15). Therefore, a consideration of different methods that account for mess, incoherence and uncertainty, are needed. Law (2004, p. 15) asserts that "we need to find ways of living in uncertainty" and this statement holds not only for professionals but for those who research professional knowing and learning concerns.

In this thesis, I have shown the value of adopting an ANT-inspired methodological and theoretical approach to address pressing educational concerns for professional practice. This relatively radical approach collapses the social and material divide, which is dominant in traditional educational research, and traces the specific connections between heterogeneous actors. Tracing these connections has made visible aspects of practice that are so often taken-for-granted, or backgrounded, in education practices.

As Fenwick (2015) argues, the purpose of a sociomaterial approach to education is not just simply to recognise the things that are involved in knowing and learning, but to foreground and analyse the specific connections between the things. However, Latour's (2010b, p. 80) concern for an ANT approach is that there is not enough focus on the different qualities, the different strength of threads, between the specific connections: "It's a great weakness for a theory to claim that every mode of connection is specific, while at the same time not being able to say in what way each mode differs from the others". He surmises that "the early intuition of ANT was right: it's just that actor-network- theory is a black-and-white rendering of associations … when what is needed is a fully *colorized* version" (p. 82, original emphasis).

In this thesis, I have sought to provide this splash of colour by drawing on more-than-Latourian concepts. I have worked with notions such as boundary objects, fluid objects, multiplicity, and aesthetic and embodied engagement to afford a richer understanding of the different qualities and strengths between connections. The imagery of patchwork and flow has also been useful to show how engineering practices are enacted in patchy, distributed, and networked ways. This layered, sociomaterial perspective has helped me to think of different ways to assemble education practices that could better prepare and support students and practitioners for work in emerging industries.

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Appendices

Appendix 1: Informed Consent and Ethical Considerations

UNIVERSITY OF STIRLING

Informed Consent and Ethical Considerations

This study has been approved by the University of Stirling's School of Education Research Ethics Committee (03/05/2012) and adheres to the British Educational Research Association's Revised Ethical Guidelines for Educational Research (2004).

In considering the ethical implications for this study, the following issues have been addressed. In working with this company, the researcher will be:

- **Unobtrusive and flexible**: The researcher will schedule with senior management the most convenient times and dates to conduct their observations and interviews before the research commences. This can be renegotiated at any point to suit the company. The researcher will remain discrete, professional and diplomatic at all times.

- **Aware of sensitive information**: The types of meetings, documents and other interactions and texts that the researcher may observe or have access to will be discussed and negotiated with senior management. The researcher will sign appropriate company confidentiality disclosures.

- **Transparent and honest:** Only people who have given informed verbal and written consent will be observed and interviewed. Participants in this study will be engineers (with project roles) with a Higher Education degree in either engineering or renewable energy. They will be asked via email if they would like to volunteer to be participants in the study. If in agreement, participants will be informed by the researcher of the true nature of the study and what their involvement will entail. It is stressed that the researcher is interested in the work *practices*, not any individual *per se*.

- **Confidential**: The participant will be informed verbally, and in writing, that:
    - Everything they say, or are observed doing, will remain strictly confidential
    - Confidentiality will be assured, and all names (people, places, projects) will be replaced by pseudonyms
    - Individual participants will have the right to withdraw at any point without consequence
    - All information will be stored securely (hard data in locked cupboards and electronic data on password-protected computers)
    - Data collected in this study is purely for academic purposes and will only be used as part of the researcher's doctoral thesis and subsequent publications and presentations.

- **Conscious of their presence:** As the researcher will be present in the office for a while, other employers not directly participating in the study will naturally have questions about who the researcher is. Therefore, senior management will be asked if they can inform all employees of the researcher's aims and details of the study via email. This information will also posted in a communal area (i.e. kitchen) reminding employees of the researcher's presence, the details of the study and contact information for both the researcher and Head of School at the university for any queries or complaints.

Appendix 2: Participant Information Sheet

UNIVERSITY OF STIRLING

Professional knowing and learning in an emerging sector: Understanding the practices of engineers in the Renewable Energy industry

A doctoral study being conducted by Jennifer Scoles at TurboUK

<u>INFORMATION</u>

From Monday October 1st 2012, a PhD researcher, Jennifer Scoles, from the School of Education, University of Stirling, will be conducting an ethnographic study at the TurboUK office to collect data for her thesis. An ethnographic study is a way of conducting research that, in this instance, aims to provide a detailed, in-depth description of everyday work practices in a renewable energy organisation. She aims to recruit participants who have a degree in engineering or renewable energy.

Her study is exploring the 'skills gap' debate in the renewable energy sector. There is a big push from policy to plug this 'skills gap' to help Scotland become a leading economic force in renewable energy. However, Higher Education is still falling short of the demands from this industry. Ethnographic data collection helps focus the researcher to explore work practices as they actually happen in the workplace, not how they *should* happen.

The data collection for this ethnographic study will invite participants to:

- Take part in three semi-structured interviews that will be arranged at a time and place of their convenience
- Be unobtrusively observed in meetings, site visits, and office procedures
- Engage in informal conversations with the researcher as and when discussions arise in the field
- Source documents to share with the researcher that are used in every day practices
- Negotiate additional ways to collect data of their work practices, such as taking photos with a mobile phone.

Only people who have given verbal and written consent will be systematically observed for the research, and engaged with in interviews. If at any time, a participant no longer wishes to be part of this study, they can inform the researcher. Any data that has been collected from them will be destroyed and they will be excluded from any further data collection processes. Anonymity and confidentiality are assured through out this study. All data collected will be stored in locked cupboards and on password protected electronic files. The researcher also emphasises that the purpose of the study is purely for academic purposes and all data collected will only be used for the researcher's doctoral thesis.

This study has been approved by the University of Stirling's School of Education Research Ethics Committee and adheres to the British Educational Research Association's Revised Ethical Guidelines for Educational Research (2004). If you have any questions or queries about this study, please contact the researcher, Jennifer Scoles (email: j.e.scoles@stir.ac.uk; telephone number 07841 655318) or the researcher's principal supervisor, Professor Tara Fenwick (email: tara.fenwick@stir.ac.uk; telephone number 01786 467611). If you have any concerns or complaints about the researcher or the research process, please contact the Head of the School of Education, Professor Richard Edwards (email: r.g.edwards@stir.ac.uk; telephone 01786 466264).

Appendix 3: Participant Consent Form

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Professional knowing and learning in an emerging sector: Understanding the practices of engineers in the Renewable Energy industry

Participant Consent Form

In signing this letter of consent I voluntarily agree to participate in an ethnographic study of my organisation's work place practices conducted by Jennifer Scoles. I understand that this study will look at professional knowing and learning in an organisation. In particular, the researcher is interested in seeing what knowledge resources workers draw upon, how technologies effect certain kinds of practice, and how the workers respond to the most challenging problems they encounter.

In agreeing to be part of this study, the researcher will:

- Unobtrusively observe me during my everyday work practices
- Engage in informal conversations with the me as and when discussions arise in the field
- Attend meetings and site visits with me when appropriate
- Take field notes of these observations and meetings
- Ask for help in sourcing documents to share with them that are used in every day practices
- Invite me to participate in two semi-structured interviews discussing my everyday work practices that will be arranged at a time and place of my convenience
- Negotiate additional ways to collect data of my work practices with me, such as taking photos with my mobile phone, if I am comfortable with this.

I grant my permission for interviews and, where negotiated, meetings, to be audio tape-recorded and transcribed. I understand that the data collected will only be used for the purpose of this study. I understand that the data, and findings generated from the data, will be used in the researcher's PhD thesis and subsequent publications, posters and presentations.

As a participant, I understand I have the right to withdraw from this study, at any time, without penalty, and any data collected up to that point will be destroyed. I am assured that the researcher has no political relationship with the workplace and the nature of the study is for academic purposes only. I understand that every effort will be made by the researcher to preserve the confidentiality and anonymity of my comments and actions. Pseudonyms will replace my name and any identifiers will be removed from my comments. My data will be stored securely in a locked cupboard or on a password-protected computer.

I understand that this study has been approved by the University of Stirling's School of Education Research Ethics Committee and adheres to the British Educational Research

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Association's Revised Ethical Guidelines for Educational Research (2004). If I have any further questions about this study, I am aware I can contact the researcher, Jennifer Scoles (email: j.e.scoles@stir.ac.uk; telephone 07841 655318) as well as the researcher's principal supervisor, Professor Tara Fenwick (email: tara.fenwick@stir.ac.uk; telephone 01786 467611). I understand I can contact the Head of the School of Education, Professor Richard Edwards, to discuss any concerns or complaints about this research process (email: r.g.edwards@stir.ac.uk; telephone 01786 466264).

I hereby grant my permission for the aforementioned in my signature below:

Participant's Signature ____________________________ Date__________

Researcher's Signature____________________________ Date__________

Appendix 4: Example of a Daily Report

Daily Report

Date: Tuesday 20th November

Location: HQ

Project Stage: Week 8, Day 2

<u>**Observations**</u>

Main Events: Design Risk Assessment conference call with Fay

Breakdowns/Improvisations: IT projectors failing at beginning

Objects and human relations involved: meeting rooms, powerpoint pres – lots of graphs and flow diagrams, hand-drawn diagrams, conference phone, see and share technologies.

Participants present: Fay

Other interactions: 2 other employees present in meeting

What I learned about knowing in the company:

Went into meeting room. Conference called into Germany. Dialled into a speaker phone. Fay checked her mobile to look up the conference call number and pin code that was assigned on the meeting request email. She dialled in and introduced everyone to the others on the line. Couldn't hear some people plus their accents, made it hard to hear them.

The guys leading the meeting in Germany logged in to See and Share (conference software) and projected on to the screen their desktop. The agenda led the structure of the meeting which had been emailed out to all those attending.

This was a hand-drawn document of a process drawing. They used their cursor to operate a highlighting tool so they could circle and point to parts of the document as they were discussing it. Couple of jokes made that this document would be developed 'properly' implying that a hand-drawn document was not considered 'standard' or proper enough to be taken seriously. Interesting idea that there is more power when something is written up using software than by hand.

After talking through the document for about ten minutes, Fay leans into the speaker phone and describes “yes, we’re all sitting around the table here nodding our heads” as it’s a speaker phone (no video link) this description is needed. Another person turns off the speaker button (muted) on order to confer in private with the team around the table what they should propose next.

Design risk assessment history: TurboHQ used to provide them until they realised that the law said they didn’t legally need to provide them. However, says clients want them and TurboUK feel they should give them to their clients, especially the big clients. TurboHQ refused to see this as a reason to provide them. Today was a landmark moment when they got TurboHQ to agree to provide these as been arguing for them for ages. When the speaker conference finished, participants were genuinely ecstatic and high-fived each other – Fay remarked that this issue had been ‘bubbling away in her gut’ for a long time.

Academic Notes

Analysis ideas: Access cards – note that access cards sit on table in meetings.

Theoretical links: Liminality – betwixt and between – Tempest and Starky – this idea about working in a threshold to link projects. Can this be used?

To think about further: Read Carlile (2002) again.

Personal Notes

What surprised me: I was introduced on conference call without having to ask.

Mistakes I made: I missed the sales meeting: Lawrence said it was at 10.15 but they collectively bought it forward and I wasn’t made aware of it

Reflections: Baking cakes for valentine’s bake sale as feel I need to give something back.

Appendix 5: Interview Questions

<u>Questions for First Interview with participants</u>

Understanding their background and training:

What and where did you study at university?

What were your motivations to study this?

Can you tell me about your HE programme? What did you study in particular?

What did 'engineering' mean to you before you began your degree?

What did it mean after?

Did this perspective change when you started this job?

What does having a job in the renewable energy sector mean to you?

Is your day-to-day job what you expected it would be like?

Can you describe to me your position in TurboUK?

What/who are the important things or people you work with everyday?

[Introduce relational map exercise]

Appendix 6: Thank-you Letter

Dear all,

I wanted to thank everybody for hosting me these past six months at TurboUK. Everyone has been so helpful and patient with me and I am sincerely grateful to those who directly participated in my PhD study and for everyone else who spared me their time for interviews, answering questions and allowing me to attend meetings.

This is my last day in the office but if you have any further questions or queries about my study, do not hesitate to contact me at j.e.scoles@stir.ac.uk. I look forward to sharing my results with you in the not too distant future.

It has been an absolute pleasure to be part of the office here – thank you. Chocolates are in the kitchen for you!

Warm wishes,

Jenny Scoles