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What Do Engineers Do With What They Know: Observing Specialized Technical Knowledge In Practice

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WHAT DO ENGINEERS DO WITH WHAT THEY KNOW?: OBSERVING SPECIALISED TECHNICAL KNOWLEDGE IN PRACTICE

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ABSTRACT

The gap between engineering education and practice has been subject to considerable research attention. We look at studies of engineering practice with a view to informing education. Our interest is in identifying technical knowledge and how it is used in practice, as well as what kind of technical knowledge is used but not taught. This paper seeks to systematically review the existing literature on engineering practice, drawing from and adding to a prior data set developed by Andrea Mazzurco and colleagues, who found that there was a gap in studies of specialised technical knowledge in practice. Investigating their dataset we found that rather than being absent, studies of practice have tended to background knowledge, by focusing on professional skills and attributes and obscuring the role of specialised technical engineering knowledge. In engineering education and practice, surveys of 'what graduates need' tend to separate out graduate attributes from specialised engineering knowledge; however, detailed, qualitative studies show the extent to which these graduate attributes are intertwined with specialised knowledge. This paper focuses on research studies that include an observational component. In total, 23 papers were analysed with a view to answering the research question: what do observational studies of engineering practice tell us about specialised engineering knowledge? We examine how knowledge was constructed by the authors, usually as socially mediated and embodied; but also at how knowledge was used by participants, generally as foundational to reasoning but in tacit ways.

1 INTRODUCTION

The gap between engineering education and practice has been the subject of considerable research attention. In this paper, we look at studies of engineering practice with a view to informing education. Our interest is in identifying technical knowledge and how it is used in practice, as well as what kind of technical knowledge is used in practice but not taught. The paper applies a systematic literature review method.

Several systematic reviews of the literature on engineering practice have already been conducted. Most notable for the purposes of this paper, the *European Journal of Engineering Education* published a review by Andrea Mazzurco and others (Mazzurco et al. 2021) that offers a mapping of the empirical research on practising engineers and seeks to develop an agenda for research on engineering practice. Mazzurco et al. (2021) analysed almost 200 peer-reviewed journal articles published between 2000 and 2018 and identified five research themes within this literature. These themes pertain to: a) how engineers learn on the job, b) what competencies practising engineers require, c) what engineers actually do in practice, d) how diversity is experienced and managed in engineering practice, and e) how engineers experience and describe themselves and their profession.

For each of these research themes, Mazzurco et al. (2021) synthesise what the existent literature offers, but also identify gaps in the literature pertaining to each theme. They find that the literature on engineering practice focuses to a large extent on what have variously been called ‘soft skills’ (Caeiro-Rodríguez et al, 2021), generic competencies (Male, 2010), professional skills (Winberg et al, 2020), or non-technical skills. This literature generally finds that soft, generic, professional or non-technical skills and competencies are integral to the practical accomplishment of engineering work.

While we recognise the importance of these studies, we argue that these professional competencies are founded on specialised knowledge (cf. Martin et al. 2005). Our purpose therefore is to pull together the literature that looks beneath professional competence to the specialised knowledge that it is founded on. In so doing, we respond to the work done by Mazzurco et al. (2021) who identify one of the gaps in the current literature as pertaining to understanding how technical (or specialised) knowledge is used in engineering practice. Investigating their dataset, we found that rather than being absent, studies of practice have tended to background knowledge by focusing on professional skills and attributes and obscuring the role of specialised technical engineering knowledge. What is clear in the literature is that technical knowledge is broader than abstract theoretical knowledge, spanning knowledge of both theoretical concepts as well as knowledge of specialised technological artefacts intrinsic to engineering.

In engineering education and practice, surveys of ‘what graduates need’ tend to separate out graduate attributes from specialised engineering knowledge; however, detailed, qualitative studies that employ ethnographic methods tend to better show the extent to which these graduate attributes are intertwined with specialised knowledge. Therefore, this paper focuses specifically on research studies that include an observational component. In total, 23 papers were analysed with a view to answering the research question: what do observational studies of engineering practice tell us about specialised engineering knowledge? We examine the problems and frameworks such studies lend themselves to, as well as how knowledge is constructed within these studies, both by the authors but also by the participants being observed.

We argue that it is important to investigate how technical, or specialised, engineering knowledge is taken up and used in engineering practice, as this may have significant implications not just for what specialised knowledge needs to be covered in the engineering curriculum, but also for how such specialised knowledge might be developed. This paper seeks to review the existing literature, to begin to address the knowledge gap identified in Mazzurco et al. (2021), and as a point of departure for initiating a process of understanding how specialised knowledge is deployed in engineering practice, and the implications this may have for engineering education.

2 METHODS

Systematic literature reviews have existed for some time and have been widely used in various disciplines. However, they are a relatively new inclusion in engineering education research (Borrego et al. 2014). Nonetheless, systematic reviews of the literature can and do fulfil important functions within this area of research: synthesising prior work, informing practice and identifying new areas for research (Borrego et al. 2014). Traditionally, a systematic literature review is conducted by using key search terms and criteria in a particular database or journal, or set of databases or journals, and appraising all of the articles in that set that meet the search terms and criteria (Grant and Booth, 2009). As the methodology has grown in use, various approaches to systematically reviewing extant literature on a topic have been developed (Grant and Booth, 2009). In this paper, we make use of the data set developed by Mazzurco et al. (2021). This is because their data set was made publicly available and has already identified the relevant literature pertaining to engineering practice published between 2000 and 2018. As such, we used this existing data set and identified those texts within it that dealt with the question of specialised knowledge. This reduced their data set from 187 texts to 64 texts. Below, we list the specific exclusion criteria applied. In addition, because the Mazzurco et al. (2021) study had only included literature published between 2000 and 2018, we repeated their search exactly, but for 2019 and 2020. This yielded an initial total of 991 search results, of which all but 21 were subsequently excluded by identifying only those studies that related to the nature and function of studies that related to the nature and function of specialised engineering knowledge in engineering practice, including those that did not explicitly focus on knowledge but in which specialised knowledge was evident, including those that did not explicitly focus on knowledge but in which specialised knowledge was evident. This meant that a total of 85 texts were found to be concerned, at least in part, with specialised or technical engineering knowledge in practice.

To limit the data set to be analysed in a systematic literature review, various exclusion criteria can be applied. These often pertain to exclusion of material published outside of a particular time period. As already noted, Mazzurco et al. (2021) focused their analysis only on material published between 2000 and 2018, and we replicated their search exactly but for 2019 and 2020. Exclusion criteria can also pertain to the content of the material found through successive rounds of title, abstract and full-paper review aimed at excluding paper results that prove not to be relevant to the analysis. This was done in Mazzurco et al (2021) and further undertaken in this study. Table 1 lists the exclusion criteria applied to arrive at the final data set of 85 studies. It should be noted that some texts were excluded on more than one basis. The exclusion criteria were applied by one of the researchers and this was then checked by a second researcher.

Table 1. Exclusion criteria

Exclusion Criteria	Mazzurco et al (2021) data set	Additional 2019 and 2020 data
Initial Total	187	991
Clearly natural or engineering science papers (not related to engineering education or practice)	0*	793
IT & software engineering, machine learning and programming	19	39
Not in the english language	0*	2
OTHER not related to engineering	0*	27
Focus on education: Learning with technology	0*	3
Focus on education: K12 schooling	0*	11
Focus on undergraduate teaching & learning	4	64
Focus on work-integrated learning at undergraduate level	0*	5
Focus on education: social and psychological factors (incl. retention)	0*	7
OTHER focus on knowledge and skills in academia, not in practice	0*	2
General professional competencies or attitudes, rankings or competency gaps	24	6
Workplace learning but not knowledge	7	1
Detailed studies of other generic competencies (eg management, teamwork, communication, ethics, design processes)	22	15
Accessing, using or transferring information, not knowledge	13	2
Competencies, with mention of knowledge but not focused on nature of knowledge (eg. lists of knowledge content or knowledge as a competency, surveys of individual needs)	3	8
Social (or philosophical), identity, disposition/attitudes, gender/sex in the workplace	22	22
OTHER focus on practice-based competencies but not knowledge	17	18
REMAINING INCLUSIONS	64	21
Observations	23	0

* These had already been excluded by Mazzurco and colleagues.

The 85 papers identified as speaking to specialised technical knowledge in engineering practice were subsequently grouped according to the methods used. In this paper, we only discuss the 23 papers that included an element of observation (of engineers in practice) as part of their research design and as reported on in the papers. The full data set is still being analysed as part of a broader systematic literature review. In this paper, we seek to answer the more specific question: what do observational studies of engineering practice tell us about the nature and function of the nature and function of specialised engineering knowledge?

The included papers were each read by at least two of the authors, who answered the following questions about each paper:

1. What is the problem or issue being addressed?
2. What is the work context (design office / supply / service etc)?
3. What conceptual or theoretical tools are used?
4. What is the focus / is knowledge foregrounded or backgrounded?
5. What methodology is used?
6. What are the key findings?
7. What implications for engineering education are drawn, if any?
8. How is knowledge constructed by the authors of the paper?
9. How is knowledge used by the participants in the research?

The answers to these questions were then grouped thematically and are reported upon in the findings and discussion that follows.

3 FINDINGS

Observational studies of engineering in practice are aimed at an array of problems or issues. Studies explicitly focused on specialised technical engineering knowledge included those aimed at understanding the use of concepts in practice (Bornasal et al. 2018), the use of systems engineering knowledge (Brooks, Carroll and Beard, 2011), and the use of mathematical knowledge in practice (Gainsburg, 2007). Other studies situated knowledge in social relations; such studies focused on newcomer participation in the engineering workplace (Johri, 2012), on graduate underpreparedness (Buch 2016), on how engineering teams share knowledge between specialities within work organisations (Baird et al. 2000; Darr 2000; Bechky 2003; Maaninen-Olsson et al. 2008; Ratcheva 2009), and on how knowledge is shared between and across projects (Koch 2004), particularly where teams are distributed geographically (Larsson 2007). A third set of studies focus specifically on the materialisation of knowledge in engineering practice, such as in the form of objects (Lee and Amjadi 2014) and in machinery and equipment (Styhre et al. 2012). Still further studies focus on how the enactment of engineering work relies on the combination of the social, the material and the embodied (Trevelyan, 2007; Trevelyan 2010; Reich et al. 2015). Because of the nature of this particular subset of the literature, some studies also seek specifically to make a methodological contribution (Baird et al. 2000; Suchman. 2000; Trevelyan. 2016). One study’s aim aligned closely with our own aim in conducting this systematic review:

despite calls for studies of engineering to pay attention to the kinds of knowledge that engineers employ, few studies have conducted detailed investigations of knowledge use in everyday engineering. As a result, the question of whether historically established or practice-generated knowledge is more instrumental in engineering work remains unresolved (Gainsburg et al. 2010:198).

The contexts in which these observations were conducted included distributed design offices contracting to RollsRoyce (Baird et al. 2000), high-tech manufacturing companies (Bechky 2003), transportation engineering consulting firms (Bornasal et al. 2018), government enterprises (Brooks et al, 2011), an engineering consultancy company with a focus on climate change (Buch, 2016), a microelectronics company (Darr 2000), structural engineering design offices (Gainsburg 2007), a research and development laboratory (Johri 2012), a major automotive company (Larsson 2007), a public medical service (Maaninen-Olsson et al, 2008), an international wafer manufacturing company (Lee and Amjadi 2014), a multinational telecommunications company (Styhre et al. 2012), and a state agency engaged in designing a bridge (Suchman 2000). The location for the research was largely the global North and West (the United States, the United Kingdom, Sweden, Denmark, Australia). One exception to this was research conducted in Taiwan (Lee and Amjadi 2014).

Methodologically, the papers were all selected because they included an observational component. However, most of the studies also incorporated other data collection techniques. Also, observation tends to be a hallmark of ethnographic research - but not all the studies included in this review labelled themselves as ethnographic in nature, though several did (Baird et al. 2000; Darr. 2000; Suchman 2000; Bechky 2003; Collin 2006; Gainsburg 2007; Larsson 2007; Johri 2012; Reich et al. 2015; Bornasa et al, 2018). Several studies were identified as using a case study approach (Maaninen-Olson et al. 2008; Brooks et al. 2011; Lee and Amjadi 2014), some with ethnographic elements (Koch, 2004; Styhre et al, 2012). The remainder of the papers were not located in any broad methodology but, in addition to observation, included several other research methods, including interviews (most of the studies), document and other artefact analysis (Bechky 2003; Ratcheva 2009; Brooks et al, 2011; Lee and Amjadi 2014; Bornasal et al. 2018), participant diaries (Johri 2012) and focus group interviews (Reich et al, 2015).

Where the theoretical and/or conceptual bases of the papers were made explicit, these tended to fall in three broad categories. A number of studies located themselves in relational, situated and/or sociomaterial approaches (Suchman 2000; Bechky 2003; Ratcheva 2009; Styhre et al. 2012; Bornasal et al. 2018). These approaches view knowledge as situational, cultural and contextual and locate knowledge within broader social and material systems. They share a view that “meaningful and effective knowledge of concepts may be more fully understood when we consider what concepts mean, why they are relevant to a community, and how they are useful to a community" (Bornasal et al. 2018: 321), and a focus on knowledge not “as a self-standing body of propositions, but identities and modes of action established through ongoing, specifically situated moments of lived work, located in and accountable to particular historical, discursive and material circumstances" (Suchman 2000: 312-313). Another common theoretical and conceptual framework employed were practice accounts of engineering work, in particular the work of Schatzki (2002; 2006; 2012) and that of Lave and Wenger (1998). These studies tended to focus on the everyday practices of engineering professionals as they engage in activity in their workplaces (Koch 2004; Larsson 2007; Maaninen-Olson et al. 2008; Johri 2012; Lee and Amjadi 2014; Reich et al. 2015; Buch 2016). These approaches view knowledge as visible in and emergent from practice, and contend that "knowledge is created and used in 'continuous' knowing processes" (Maaninen-Olson et al. 2008: 261). A third category of frameworks employed are systems perspectives (Baird et al. 2000; Brooks et al. 2011). These approaches are ecological in focus and draw on the idea of systems engineering methods. Other approaches drawn on include interpretive frameworks (Darr 2000; Trevelyan 2007; Trevelyan 2016), the concept of mathematical dispositions (Gainsburg 2007), and a behavioural approach (Gainsburg et al. 2010).

4 DISCUSSION

A minority of the studies in our review view knowledge from a knowledge management perspective (Baird et al. 2000; Maaninen-Olson et al. 2008; Ratcheva 2009). These studies tend to either view knowledge as a black box, thus not theorising it in any way (Ratcheva 2009), or to reify knowledge as something that can be 'transferred' or 'shared'. For example, Baird et al (2000) find that technical information and data about products, including experience of past successes and failures (what we would view as experiential knowledge) is informally transferred through conversations within informal social networks. However, Maaninen-Olson et. al (2008), despite locating their research in a knowledge management perspective specifically argue that knowledge is connected to context and that it should not be viewed as an independent object. Instead, they argue, knowledge is distributed in tools and artefacts

Indeed, the view that knowledge is distributed - in people and in objects - was prevalent in our study. Bornasal et al. (2018) argue that conceptual knowledge is distributed in the world and facilitated around material resources. Similarly, Lee and Amjadi (2014) argue that objects trigger meaning-making (which facilitates problem solving in engineering), foster spontaneous relationships (which encourages cooperation and negotiation) and engender real-time exploratory action (which expedites troubleshooting processes). In so doing, they use the concept of knowing through objects to describe the role that objects play in engineering work. Styhre et al. (2012: 151) show how "engineering work is based on distributed know-how and joint collaborations, emerging as a patchwork of activities where one single person may know a lot, but not everything, about the technology-in-the-making".

Another characteristic of knowledge prevalent in our review is the view that knowledge emerges through participation and interaction within a joint enterprise (Johri 2012). As Bornasal et al. (2018: 321) argue: "knowledge becomes a dynamic reconstruction of a world that is dependent on participation and interaction within a community". Johri uses the view of knowledge as both distributed and socially-mediated to show that newcomers into an organisation make use of both social (interpersonal) and material (information technology) resources to create sociomaterial assemblages that foster success in moving toward full participation in the organisation. Similarly, Bornasal et al. (2018) find that engineers expand their individual understandings of a concept by engaging in social negotiation of meaning.

These findings related to knowledge have two important implications. The first of these is that knowledge is transformed, rather than transferred, through socially-situated sharing. Bechky (2003) shows this in their finding that members on a production floor worked to transform the understandings of others in order to generate a richer understanding of production problems. This, Bechky (2003: 317) argues, “generated a more broadly shared understanding that allowed for the knowledge to be used across the organization”. A second implication is that specialised engineering disciplinary knowledge bodies, such as mathematics, are embedded in knowledge but are not knowledge in themselves. Gainsburg (2007) argues that mathematics is a tool (used sceptically with reverence) recruited for the purpose of making design decisions (in the form of engineering judgement) towards the production of something other than knowledge. As Gainsburg (2007: 498) explains:

Mathematics is the mandatory language for design and analysis and mathematical proof the industry standard for final justification. The end products of structural work are a symbolically expressed design and a story about how that design came to be. That story, told through calculations and mathematical proof, is a dramatically revised history of the design process, one that erases nearly all traces of iterations, missteps, and rejected methods, many of the modeling assumptions, and some instances of engineering judgement.

A final key perspective that emerges from the papers included in our dataset is the view that knowledge is socio-culturally regulated (see, for example, Brooks et al, 2011). Koch (2004) shows how knowledge-sharing can be hindered by organisational cultures when a culture of ‘getting things done’ – what Koch (2004) terms the tyranny of projects – cross-project learning and knowledge sharing are hindered. A key implication of this is outlined by Trevelyan (2007), namely that a large part of the work of the engineer is technical coordination, which Trevelyan (2007: 194) defines as “working with and influencing other people so they conscientiously perform some necessary work in accordance with a mutually agreed schedule”.

5 CONCLUSIONS

The papers included in our dataset present several implications for engineering education. They demonstrate what many engineering educators have long argued: that knowledge is more than mere content, that it is embedded in the artefacts and everyday activities of engineering, and that knowledge is distributed among people and artefacts and, as such, socio-culturally mediated. A majority of the papers surveyed call for greater focus on engineering in context. For example, Bornasal et al. (2018:319) suggest “activating and developing students’ knowledge of concepts with regard to the complexities of real-world contexts [in order to] bridge the gap between the classroom and the workplace”. Similarly, Gainsburg (2007) identifies a need to “present a more realistic view of the role of mathematics in everyday occupations and to counter the damaging perception of mathematics as quasi-divine”. This can be achieved through “solving a nonmathematical, real-world problem, rather than doing or learning mathematics per se”.

This has implications not only for curriculum design and pedagogy, but also for the way we frame how engineering work is understood for students. Some papers argue against the individualised view of the engineer as the ‘hero’ designer, as this is counterfactual to the way engineering knowledge is produced, shared and disseminated in engineering practice. For example, Trevelyan (2007) argues that the "notion that an engineer has to be engaged in technically challenging work to create value … seems to be a pernicious misunderstanding that can undermine many engineers’ self-esteem”. This would suggest that engineering curricula should foreground the social, material and distributed nature of knowledge in practice.

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