PROFESSIONAL PRACTICE AND EDUCATION

Engineering Professionalism

Engineering Practices in Work and Education

Ulrik Jørgensen and
Søsser Brodersen (Eds.)

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Engineering Professionalism

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Scope

Professional Practice and Education aims to provide a forum for perspectives of our understanding of the nature of professional practice and the consequences flowing for education in the professions. It is the intention of the Editor that a platform will be provided for contributors from diverse cultural backgrounds, so that, on a global level, the nature of professions and their cultural/historical positioning might be problematised and re-examined.

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ULRIK JØRGENSEN AND SØSSER BRODERSEN

1. INTRODUCTION

The Practice Turn in Studies of Engineering Work and Education

INTRODUCTION

The research and discussions presented in this book provide analytical frameworks and case studies on how institutional and practical settings in engineering education and professional work are entangled and mutually dependent in co-shaping or co-construction processes within different domains of engineering. In order to demonstrate these essentially dynamic features, the empirical material is aimed at unravelling the interrelatedness of educational and work practices in engineering and analysing them as inherently situated in order to understand how engineering professionalism is produced.

The view of a certain linearity whereby education has to prepare students to fulfil professional job requirements orients educational planning towards producing the competences needed and articulated by employers. This view draws on a metaphorical reference to supply and demand which is questioned from the outset of this analysis. Educational settings may produce knowledge and skills that complement or sometimes only partially provide the competences required in many job situations. At the same time, professional practices and routines may ultimately restrict the visions and competences developed in the educational setting.

The perceived 'gap' between education and work is therefore questioned, and the contributions herein demonstrate that such a perspective neither supports the development of new perspectives through what is often termed 'engineering educational reform' nor provides an accurate account of how learning, innovation and new job practices relate and emerge. The approach taken in this book is to engage in studies of practices as they develop in co-existing sites of education, work and professional discourse as well as on different scales, and to open avenues for understanding how they contribute to dynamics in the production of engineering professionalism.

AIM OF THE BOOK

Although the aim is to demonstrate the inter-linkages, the thematic structure of the book follows the institutionally well-established divide between education and professional work. While the individual chapters take either the education

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or work context as a starting point, the analyses reveal many crosscutting issues that demonstrate the complex relationship between education- and work-related practices. This provides a basis for addressing conclusions directed towards the different sites and their roles in shaping the performed practices.

Studies of engineering in these different but inter-related settings are motivated by the following questions:

- How can we understand different engineering practices and how do they relate?
- Which dimensions facilitate transitions between educational practices and work practices?
- Where is engineering professionalism learned and the engineering 'mindset' constituted?
- How does engineering professionalism change in response to societal challenges?

In this book, the term professionalism refers to what we have introduced as professional practices – activities related to the work and study of engineering analysed through the perspective of the 'doings and sayings' of engineering professionals. The relationship of engineering to other professions and its societal status (a topic that is often explored in studies of engineering as a profession) is not a primary focus in this book, even though it is included in examinations of the practices of engineering institutions and their framings of engineering.

The concluding chapter synthesizes the answers to these questions and the lessons learned from attempts to develop engineering in the different settings studied. It highlights the linkages among them, drawing on findings and details from the individual chapters as well as the literatures in which they are situated, showing how the different sites interact and produce specific representations and frameworks central to engineering professionalism.

WHY THE FOCUS ON PRACTICES?

Throughout more than a century scholars have explored the field's contributions to technological and societal change, and the role of engineering education. Scholars have examined engineering achievements based on personal accounts, professional identities using a sociological approach, the role of engineering in specific forms of government based on political science, and the role of engineering in innovation based on historic accounts. Moreover, scholars have focused on ethical and political dilemmas of engineering vis-a-vis societal impacts of technological change and the very nature of engineering based on speculative and philosophical reflections (for an overview see e.g., Jørgensen, 2010) These varied accounts have produced images of engineering that tend to be quite idealized and even stylized presentations of these professionals and their activities. The result has been accounts that to a large extent support popular images of engineers as heroes of innovation and progress, servants to industry, or technocrats with limited insights into social matters. While such studies have shed light on certain institutional and professional aspects of engineering, they have provided less insight into how engineering is performed in different sites.

Critique of these hitherto dominant accounts has sparked increased interest in opening the black box of how practitioners perform engineering. Studies from the 1980s and 1990s of engineering educational programs and professionals demonstrated that the knowledge and skills taught in engineering schools seldom came to be used in work situations as straightforward problem-solving tools. These studies were instrumental in pointing to a 'gap' between the knowledge that is taught and the knowledge in use, paving the way for a model of the relationship between education and work that frames these sites as separate, with their own rationales (Jakobsen & Jørgensen, 1984). One productive outcome of these studies was a discussion about the translation versus the transfer of knowledge, which led to pedagogical and didactic reforms, including attempts to make project- and problem-based learning core to engineering, and to incorporate more complex and authentic problems in curricula. These new perspectives paved the way for an increased interest in better understanding 'what engineers do' that led to a new focus on engineering practices (Downey, 2005; Kolmos et al., 2007).

It also resulted in a renewed interest in the study of engineering practices with an emphasis on the role of practical vocational knowledge as well as the importance of other forms of knowledge pertaining to real life engineering challenges. Thus, scholars began to study the practices involved in performing engineering as a multifaceted professional task (NAE, 2005; Jørgensen, 2007; Grasso & Burkins, 2010).

THE PRACTICE TURN IN ENGINEERING STUDIES

This interest in engineering practices has emerged in several publications in recent decades. The body of literature constituting the new approach to studying and understanding engineering includes a number of studies that seriously consider the role of technical design concepts, practical experimentation, and the challenge of scaling. An example of this is Vincenti's (1990) book, *What Engineers Know and How They Know It*. Afterwards, scholars published studies of the role of drawings as an important part of engineering design and communication (Ferguson, 1994; Henderson, 1998), and the role of design dialogues and object worlds (Bucciarelli, 1994; Vinck, 2003). In another line of practice studies, scholars focused on other aspects of engineering related to the importance of engineers' life worlds (Mellström, 1995) and the role of communities of practices in engineering and how engineering work organizations operate (Kunda, 2006; Barley, 2005; Barley & Kunda, 2004).

In a publication edited by Williams, Figueireda and Trevelyan (1994), the practice perspective was used as the core approach to study engineering work in line with our intentions for this book. The studies included here reveal the need to account for the realities of practice, including both the social and the technical aspects of engineering and their interaction.

We also include the new field of research called 'Engineering Studies', which is distinct from and builds on the fields of 'Technology Studies' and 'Science Studies' and contributes to the practice turn. In his article, 'What is engineering studies for? Dominant practices and scalable scholarship', Gary Downey (2009) provided an overview of some of the very basic and important findings that studies of engineering practices have contributed in recent decades.

The core of an engineer's identity lies in the ability to solve problems by using mathematical tools. This is a dominant image, a taken-for-granted and non-discussed trait of the engineering profession (i.e., what engineers are able to do) and the most important pedagogical strategy (i.e., teaching engineering students how to solve problems in a very particular way through the use of mathematical tools). Many of the discussions on how to improve engineers' professional capacities focus on additional requirements, not whether the core competency should be re-worked. Moreover, there is little discussion of how non-engineers are excluded from the definition of problems to be solved as well as how it disregards other disciplines that now claim jurisdiction over technological development, such as the sciences. Whereas practical training historically has been at the core of engineering education, the enormous expansion of engineering programs in poor countries has sparked a trend toward focusing only on the theoretical problem-solving aspect and abandoning laboratory training and practical skills development.

At the same time, Downey stated that engineering educators have begun looking beyond engineers for curricular help to an unprecedented extent to prepare engineers not only for local contexts, but also for global contexts, which is one of the main challenges currently faced by engineering educators. Downey also referred to scholarly work on how engineering includes myriad negotiations among forms of engineering knowledge, strategic activities of heterogeneous agents, specific territorial formations, monetary distributions, etc. This also applies to the idea of career path development and to engineering students' actively involvement in constructing their identity as they struggle to adjust to the culture of problem solving within engineering.

THE PROCEED PROJECT AND ITS FINDINGS

Contributions to this book are the outcomes of collaborations among Danish, Nordic and American researchers brought together by a research project funded by the Danish Strategic Research Council. The question that motivated the research project 'Program of Research on Opportunities and Challenges in Engineering Education in Denmark' (PROCEED) was: How have important and pressing societal challenges influenced engineering education and the professional work of engineers? Research findings indicate that uptake processes are slow and often end up transforming the challenges. Based on these project findings, which were presented in a series of seminars, this book presents attempts to identify and discuss how current practices in engineering, institutional planning, education and work can contribute to our understanding of how the engineering profession might be changing. The contributions presented in this book continue the discussion and present some of the findings resulting from specific studies of practices.

The PROCEED research project's basic assumption was that engineering professionalism is produced and reproduced in different, but mutually constitutive institutional contexts: institutional settings concerned with the reproduction of engineering knowledge and skills (i.e., engineering education and research), and companies and professional organizations concerned with the application of engineering knowledge and skills in work practices.

Core elements of transformation within the engineering profession include the recent focus on environmental issues and increasing attention to the impacts of climate change and sustainability as well as the renewed emphasis on design skills in engineering. An outcome has been the creation of new design programs at engineering schools (e.g., Delft University in the Netherlands, Rensselaer Polytechnic Institute and Stanford University in the United States, as well as the Norwegian Technical University, the Technical University of Denmark and Aalborg University in Denmark). These educational institutions are responding to product development and innovation demands (e.g., a focus on user involvement and sustainability) from society and industry in the context of globalization and new cooperative initiatives. Scandinavian countries are known as the breeding ground for the participatory design approach that strives for fairness and user influence in design processes, including changes in organizational relationships, processes, etc., which is a primary reason why the PROCEED project originated there.

Another set of challenges to engineering education and practice can be found in the demand for innovation and business orientation – what in recent decades has been incorporated under the umbrella of 'entrepreneurship' across countries in response to the central role of innovation and new ways of applying techno-scientific results. Demand for more knowledge among engineers related to industry practices and the economic aspects of innovation (i.e., 'the business case') has existed for a long time. The new perspective that is included in the 'entrepreneurship' challenge asks engineers not only to understand economics and business organization, but also to adopt new ways of working with innovation and to bridge technical knowledge and applications in business and society (Jørgensen & Valderrama, 2012). These developments serve as the backdrop for this book.

BOOK CONTENT OUTLINE

The first three parts of the book focus on three of the sites constituting engineering professionalism: institutional policy, education, and work. All chapters build on empirical studies of practices that help shape engineering professionalism. The fourth part of the book synthesizes the findings from the first three parts.

In *Part 1*, which focuses on institutional practices, Atsushi Akera and Xiaofeng Tang contribute with two chapters. The first, *Chapter 2*, focuses on governmental conceptions of engineering educational planning. The first is the workforce supply provision perspective of the 1950s and 1960s based on ideas of prediction and institutional positioning and the notion that society can provide the knowledge and specializations needed through institutional and disciplinary investments and planning efforts. The second, fostered in the 1980s, is rooted in a neoliberal market-based model where institutions are given more space to develop programs and the necessary research and innovation base.

In *Chapter 3*, they present an analysis of the strategic positioning of five Danish engineering schools (institutions) based on data from site visits and interviews. The analysis shows how institutions assign different weights to a multitude of strategies, resulting in different relationships among disciplinary priorities, engineering profiles, and priorities assigned to research and innovation. Reforming education and meeting societal challenges through new programs and disciplines are only two among many institutional concerns. The neoliberal concept of accreditation and the common framework resulting from the European Union's Bologna process demonstrate the importance of branding and innovation strategies.

Part 2, which is about educational practices, includes *Chapter 4*, written by Andrés Valderrama, Søsser Brodersen and Ulrik Jørgensen. Their study combines a historic investigation into how existing codes of meaning constructed within established educational programs and research disciplines have shaped the uptake and translation of societal challenges in the fields of environmental protection and energy since the 1970s at the Technical University of Denmark (DTU) and at the newer Aalborg University (AAU). These translations have divided a societal crisis into known disciplinary contexts by transforming them into operational objects that fit existing engineering divisions of labour. The recent decade's sustainability challenges have resulted in a renewed focus on climate change and resource scarcity that once again has raised questions about their uptake in engineering. The analysis demonstrates that modelling issues are constituted as new disciplines, while social interaction and change agendas are opposed by established disciplinary traditions.

In *Chapter 5*, Karen L. Tonso explores how engineering identities were at play in efforts to re-incorporate design as an important part of engineering education at an engineering school in the United States during the 1990s. Her analysis shows that despite good intentions, the inertia of the engineering education culture spilled over into a design setting by framing the conditions of possibility. This setting thus did not simply balance out the identity formation dynamics that take place on campus. She shows these dynamics by tracing how members of a design group behaved in a collaborative project with a professional engineer when they actually went to the plant where the engineer worked and conducted a number of tests for their engineering design project. This illustrates how capstone projects confirm or challenge the identities engineering students form as they pursue their studies. Tonso emphasises how instrumental, objectivistic, and abstract goal orientation fosters student identities that appear contradictory to the visions embedded in reform strategies for learning and cross-disciplinary integration.

In *Chapter 6*, Anne Katrine Kamstrup studies how the CDIO (Conceive, Design, Implement, Operate) framework was deployed at two institutions in Denmark: the Technical University of Denmark and the Aarhus University School of Engineering. Her main point is that administrators, engineering educators and students envisioned and enacted CDIO in different ways. Students did not embrace the CDIO structure, but regarded it as a 'cute' pedagogical pirouette that was less relevant than the dominant elements in education (e.g., exams and reports). The educators viewed it as a challenge to existing educational programs with the prescribed mix of project assignments and coursework, and did not fully implement it as disciplinary norms and testing practices prevailed.

Nathan Canney's study in *Chapter 7* is rich in detail about the motivation of four students to join new service learning initiatives in local communities and pursue careers in that direction. He emphasises the disconnect between students' aspirations and the professional advice given to them. The result is that only one of the four students actually dedicated her career to working on development projects, while two others ended up in typical engineering jobs 'to gain experience' and the fourth left engineering altogether. Canney illustrates how engineering students are provided with opportunities to engage in development projects, but that these opportunities dwindle when they become professionals partly due to a lack of preparedness to cope with the problems facing them in contexts often characterised by restricted professional norms and divisions of labour.

Part 3 is devoted to work practices as the analytical starting point. In *Chapter 8*, Anders Buch follows a groups of engineers in a consulting company attempting to turn engineering work practices towards more holistic practices. Though reforms in engineering education tend to favour such practices, conditions and circumstances external to practitioners' knowledge and skills are crucial for such changes. The article demonstrate how the practice landscape frame and limit the enactment of holistic work visions.

In *Chapter 9*, Rikke Premer Petersen and Anders Buch highlights the processes of design as material and conceptual practices that challenge conventional engineering approaches. They demonstrates how an existing and rather conventional mass-producing car manufacturer with well-established work procedures and standards for the division of labour was challenged by new needs and perspectives emerging from designs for the next generation of cars. In these designs, user experience is an important but difficult to identify quality used to market cars to high-end customers; at the same time, it is a potential competitive parameter that incorporates other elements into the core design. Introducing new design methods also implies networking and translating them to other parts of the company to legitimize and translate the approaches and legitimate new staging practices.

In *Chapter 10*, Søsser Brodersen and Hanne Lindegaard uncover a variety of ways in which users are represented in a medical company's innovation, test and sales activities. These representations are constituted at the intersection of disciplinary practices, company procedures, user relations in terms of confidentiality and distance, competences of the involved engineers, and the ways data can be produced to mediate information between different parts of the company and different values assigned to data.

Chapter 11 presents a case study by Lars Bo Hendriksen on the largely wicked and undefined problems around the development of a manipulator in a wind turbine company. As new framings and organisational conceptions emerged, the object of engineering design and practice was re-defined and re-formatted to fit different managerial and utilisation contexts within the company in question. As an 'actant' within a network of socio-technical relations and with an agency of its own, the manipulator played an active part in reconfiguring and reconceptualising problems.

Vivian Lagesen presents a cross-cultural study of software engineers employed by software consulting companies in Norway, Malaysia and California in *Chapter 12*. She uncovers rather contradictory elements concerning values, gender norms, and dominant societal discourses related to gender and software engineering. While feminist scholars have characterized the field as masculine, her study reveals contradictory results. The study reveals the limitations of the idea of gendered practices resulting from basic characteristics of disciplines. It shows how societal structures, cultures, and discourses are crucial, and may even lead to counterproductive results. It also demonstrates the limitations of recruitment strategies that do not reflect changes in educational and work practices performed in education and work.

Part 3 concludes with *Chapter 13*, in which Joakim Juhl demonstrates the continued tensions between the vision of building straightforward mathematical models and the experiences of using them in production management practices. The context and organizational framing of the two work practices sustains this critical relationship. The study reveals that physicists and engineers have different priorities and produce rather different forms of knowledge and results to which no common legitimacy is assigned. On one hand, engineers seek professional credibility by transforming their modus operandi towards that of science, while physicists, on the other hand, pursue professional utility through extra-academic collaboration.

Part 4 is comprised of a single chapter. In *Chapter 14*, Ulrik Jørgensen and Andrés Valderrama synthesise lessons learned from the contributions presented in this book and reflect on how the presented studies of practices challenge how the engineering profession operates and how the perceived relationship between education and work is simplistic and results in problematic advice. In this chapter, the authors illustrate how the contributions demonstrate the challenge of translating societal challenges into engineering practice in education as well as in professional work situations. They discuss how institutional frames at different levels govern perceptions of the objects of engineering, how practices transform, and how engineers' identity formation is a result educational frames, societal norms, and visions for outcomes of engineering and technologies. They further describe achievements concerning the application of practice studies and conclude with reflections on the crosscutting findings related to controversies about the knowledge base of engineering, the interrelationship between education and professional work, as well as responses to the societal challenges faced by members of the engineering profession.

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PART 1

ENGINEERING INSTITUTIONAL PRACTICES

ATSUSHI AKERA AND XIAOFENG TANG

2. UNDERSTANDING EU AND DANISH HIGHER EDUCATION GOVERNANCE THROUGH A COMPARISON WITH US REFORMS

INTRODUCTION

In this contribution, we describe the changing landscape for higher education in Europe and Denmark under the Bologna Process, as viewed through the eyes of two historical case studies in US higher education reform. Our focus will be on governance. As a quintessential public good, higher education has always been within the province of the state. Nevertheless, educational institutions have long served broad economic objectives, where the state has played an active role in both financing and structuring higher education in ways specifically designed to support goals such as workforce development and the transition towards a supposedly ever increasing "high-tech" and "innovation" based economy. While traditionally these decisions have been made by state educational bureaucracies with the co-involvement of the legislature, the ascent of neoliberal economic doctrine and its practical manifestations within the educational sector have transformed the decision making process, as well as the institutional policies and structures designed to achieve meaningful alignments between public and private interests.

In this chapter, we open with a brief review of neoliberalism and present two US case studies that document the rise of neoliberal modes of higher education governance. After drawing out an analytic framework based on these studies, we apply this framework to assess both the extent and limits of neoliberalism as it has manifested itself within the Bologna Process, and the Danish national response to the Bologna Process in the realm of engineering education.

OUR APPROACH

The two US case studies that we introduce here are the 1960 Master Plan for Higher Education in California, and a second, state-wide study conducted during the midst of the Reagan-Thatcher Era in the state of Texas. Both were significant developments in the successive restructuring of US higher education. The 1960 Master Plan, as politically orchestrated by the President of the University of California system, Clark Kerr, firmly established a tripartite system for higher education within the state that

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produced one of the world's most envied systems of public, higher education. Texas' Select Committee on Higher Education, meanwhile, provides us with an explicit instance of higher education reform as driven by neoliberal social and economic policies. The contrast between the two case studies, in terms of governance, is quite striking. The California Master Plan came into being through structured negotiations carried out between well-established higher education bureaucracies comprised of the University of California system administration and California's State Board of Education. By contrast, Texas' Select Committee was a voluntary and largely lay body charged with charting a future for the state's higher education institutions while contending with entrenched political interests.[1]

Despite this contrast, it will remain important to pay attention to the underlying similarities that drove these two initiatives. In fact, very similar issues of demographic changes, regional differences, fiscal crisis, and the evolving economic interests of the state provided the underlying impetus for change, and in a manner not dissimilar from the broader circumstances that produced the Bologna Process. Nor could any discussion about higher education be limited to matters of economic development alone, for many civic concerns beginning with educational access and social mobility necessarily surfaced during the associated conversations. Given the strong, social democratic traditions in Denmark, as well as in many of the other signatories to the Bologna Declaration, how different social priorities are weighed and integrated into political and institutional processes under changing regimes of governance will be an important focal point of our analysis.

This work was carried out as a sub-project of PROCEED. Our task was that of documenting the institutional responses to the changing policy environment for engineering education in Denmark, and to do so through a set of site visits fashioned after a US-style external program review. Altogether, we visited four Danish universities and engineering colleges at five locations, specifically Aalborg University's northern campus, Aarhus University and Ingeniørhøjskolen i Århus (IHA), Ingeniørhøjskolen i København (IHK), DTU, and the new Copenhagen Campus of Aalborg University. The visits occurred in October of 2012. Our account is based primarily on the information conveyed to us during our site visits. The latter half of this chapter will focus on our broad observations of the changes in Danish engineering education; the specific institutional responses, meanwhile, are described in Chapter 3. Given the limited scope of our visits, knowledgeable observers will want to view our findings more as an account of how our interview subjects chose to present their own history, as opposed to it being a full and accurate history of the relevant events. Still, it is our assumption that our observations provide a fresh perspective from which educators and policy makers can reflect on the changes they themselves are experiencing. Such is the advantage of any external review. This being said, we fully expect that our findings will contain errors of fact and of omission, especially as they relate to the broader policy context.

TRADITIONAL AND NEOLIBERAL MODES OF GOVERNANCE IN HIGHER EDUCATION

John Aubrey Douglass, in his historical account of California Master Plan for Higher Education, describes how the key to California's success was a strong, semi-autonomous system of higher education governance as anchored by a constitutionally recognized board of regents for the University of California system. Though equally troubled by the changing fiscal picture for US higher education in recent times, Douglass expressed the worry, at the end of his study, that,

> *State lawmakers and the education community have not addressed the fundamental questions in the 1990s… the political culture of optimism has faded. State and local governments appear impotent to effect change, and the pressures of a rapidly growing and diverse population have set a new stage.* (Douglas, 2000:324)

However, advocates of neoliberal educational reform may well reject this conclusion. Those who call for introducing greater market competition between universities by "re-engineering" higher education and for introducing new metrics designed to "improve student experience" hope that a very different political economic regime will induce positive changes. This new regime builds on the neoliberal push to introduce market mechanisms and accountability into public institutions of higher education with the hopes that this will produce stronger educational systems while simultaneously containing the costs of higher education.

From the point of view of the grounded analysis that animates this volume as a whole, it is in fact important not to cast either of the following US case studies as ideal types. There will be those who will recall the vehement protests directed at Clark Kerr for transforming the University of California into a "knowledge factory."[2] Entrepreneurial conduct and economic concerns about workforce development were critical elements in the origins of the California Master Plan; market-oriented conduct in higher education certainly did not originate with neoliberalism in the United States. And while some administrators may be eager to apply the latest measures of educational accounting and accountability, others remain sceptical about the efficacy of such techniques, and of "quality assurance" regimes that transform students into customers. The very question of what constitutes a "better" outcome is itself a significant point of contention, with various actors—both then and now—taking on different stances that range from research and excellence, to equity and access, workforce development, and the waning view that higher education should continue to represent something more than the economic desires of the state.

Given that we are foregrounding the question of governance, and the neoliberal turn in the second case study and its potential relevance to more recent developments in Denmark, we begin with a review of the scholarly literature on neoliberalism. While it may seem odd, at least to the uninitiated, to speak about neoliberalism with regards to what some consider a quintessential public good, neoliberalism has never been about the removal of the state. As contrasted against the laissez faire policies of classic liberalism, neoliberalism has from its outset been about a rearrangement of state and private institutions. While some still see in neoliberalism a reduction in the role of the state – a contraction in government services designed to limit the role of the state to that of preserving market institutions – others see the process as one of redeployment, one in which the state may even significantly expand its activities in the name of promoting and protecting market interests.[3]

Renowned critics of neoliberalism such as the economist Joseph Stiglitz have declared neoliberalism dead (Stiglitz, 2008). However, although neoliberalism may have lost credibility among some academic economists, it has continued to circulate as a form of policy and, equally significant, a body of practice. The Marxist geographer, David Harvey, among others, has also made a distinction between theoretical and practical neoliberalism, with the latter referring specifically to concrete, and often politically motivated reforms undertaken in the name of neoliberalism. Others have turned to a study of the detailed practices of neoliberalism, including the routinized bureaucratic practices designed to actualize neoliberal policy intent (Vaquant, 2012:66–79). This can be seen, for instance, in the US engineering accreditation organization, ABET, and its turn from quantitative accreditation standards to "outcomes assessment," or the Bologna Process and its emphasis on "quality assurance."

Within the Foucauldian notion of governmentality – which focuses on the general coherence of the ideological regime set up by neoliberal ideas and epistemic practices as opposed to any pure and complete implementation – it is fully understood that neoliberal principles can be extended into state entities, including state systems of higher education. Thus, even as the public responsibilities of the state remain in the foreground – the education of citizens, the creation of a productive workforce, maintaining a path for upward social mobility – market mechanisms are introduced into public bureaucracies in ways designed, or at least intended to increase their efficacy in achieving these ends. Universities are encouraged to compete with one another for students; develop and introduce new instruments for outcomes assessment; redefine degree programs and reallocate faculty lines in more cost effective ways. Both the boasted achievements and the prevalence of faculty complaints indicate that such market reforms have found broad expression within higher education in recent decades. These reforms are clearly present within the Bologna Process.

Still, one of the dangers of a focus on governmentality is that once one dons this analytic lens, the scholar's own ocular vision becomes rapidly narrowed to those aspects of institutional conduct that work primarily to affirm the postulated ideological orientation. This danger is amplified by the promiscuous interpretation of neoliberalism as viral and adaptive, as found for instance in Aiwha Ong's studies (where the interpretation is justified) (Ong, 2007:3–8). If the unfolding of market mechanisms within the context of state institutions are known to have their limits, what is to say that older, political and bureaucratic forms of governance do not remain dominant, and are in fact the more important means for achieving the civic goals that remain, if they do, at the heart of educational institutions? Still, Douglass may be right in lamenting the recent turn of events, if we have seen the atrophy of traditional higher education governance structures that were designed to keep market interests at bay.

This is the kind of concern that has prompted scholars in other areas to recommend that we turn to more empirical methods in documenting "actually existing neoliberalism" (Hilger, 2010; Vaquant, 2012). Both historical and ethnographic methods, including interview methods, remain an important means of documenting how and to what extent a rearrangement in the relationship between state and private institutions has taken place. Within the realm of higher education, we need to pay specific attention to the following:

- Documenting the actual neoliberal, market-oriented practices in higher education, including, where possible, their origins and effects,
- Conversely, describing the extent to which traditional political and bureaucratic processes continue to dominate the conduct of our institutions for higher education, and this at various different levels within an organization,
- Taking note of the extent to which other values, such as educational access or social mobility, continue to animate conversations in ways that limit neoliberalism's discursive sphere, and
- Noting the extent to which market-oriented conduct within educational institutions antedates the rise of neoliberal economic doctrine, and conditions its uptake.

The last of these items does not necessarily undercut a neoliberal interpretation, in that established practices may acquire new life and vitality through the infusion of new economic thought. Nevertheless, any critical assessment of neoliberalism's accomplishments must take into consideration how antecedent practices become folded into new social movements in ways that enable new economic doctrines to exert influence within a specific social and economic sphere. This is what we set out to accomplish in this study. We do so by first turning to the pair of US historical case studies.

DOCUMENTING THE NEOLIBERAL TRANSITION THROUGH US CASE STUDIES

We draw on two historical case studies from published studies as well as our own research to both illustrate and flesh out our ideas about alternative and hybrid modes of higher education governance. A comparative analysis of the two cases will then provide us with an analytic framework, grounded in specific issues and practices, for evaluating recent developments in Europe and Denmark from the standpoint of governance. The comparative analysis will also give us a grounded understanding of the rise of neoliberal modes of governance and their significance in US and European higher education.

The 1960 Master Plan for Higher Education in California

The 1960 California Master Plan is probably one of the most important documents in the history of higher education policy in the United States. It was the product of demographic changes and the rapid post-war economic expansion of the state, as paired with a progressive social vision and a favourable post-war situation within the state's treasury. Many in the United States feared that there would be a post-war recession at the end of World War II. Given the large number of returning veterans, a decision was made to soften their impact on the labour market by encouraging veterans to continue their studies. While the national manifestation of this policy was the 1944 federal G.I. Bill, the State of California was in a favourable position to extend the policy considerably further due to a flush treasury filled with taxes collected as a result of war production. As spearheaded by the progressive Democratic governor, Earl Warren, a basic decision was made to provide tuition-free access to higher education to all qualified residents within the state. Elements of a tripartite system actually preceded the 1960 Master Plan, with the University of California system, the California State Colleges (former teacher training colleges), and a smattering of junior-colleges all in existence before World War II. These different systems helped to absorb the returning students and channel them into appropriate levels of education (Douglas, 2000:190–197).

War production also produced a demographic explosion within the state, a trend that continued in the post-war period due to Cold War defence expenditures and the general strength of California's economy. Between 1940 and 1960, California's population rose from 6.9 to 15.7 million people, and would continue to rise to nearly 20 million people a decade later.[4] This population expansion and the associated speculation in real estate created political pressures to create additional campuses within all three higher education segments, especially given the demographics and aspirations of this younger, mobile population. Because the University of California remained committed primarily to research and excellence, the main expansion occurred within the Cal State Colleges. In 1947, the State Legislature officially recognized that the Cal State Colleges were general purpose colleges, and not just institutions dedicated to teacher training. The University of California, in turn, began expanding its multi-campus system in response to the expanding size and role of the Cal State system (Douglas, 2000:188).

In the case of California, established institutions and governance traditions determined the course of events. Indicative of the strong educational bureaucracies that existed within the state, legislators were unable to simply spearhead a proliferation of state college campuses. Being former teacher training colleges, the state colleges were overseen by the state Department of Education and its Division of State Colleges and Teacher Education. While there had been a history of conflict between this Division and the University of California President's office, given their mutual concern about the proliferation of campuses and the associated risk of dispersing academic resources and talent, the two began working more collaboratively to limit the construction of new campuses. The result was a series of studies, consisting of the 1948 Strayer Report, the 1955 Restudy, and a pair of related studies and agreements in 1953 and 1958 that dealt directly with the engineering workforce requirements of the state. Of these, the 1948 Strayer Report was most instrumental in establishing the principle of the tri-partite system. Utilizing economic metrics as well as an argument about economies of scale, the report defined the appropriate sphere of responsibility for each institution and specified the minimum and maximum size for each Cal State and University of California campuses (Douglas, 2000).[5]

This is not to say that entrepreneurial conduct had no place in the post-war reshaping of California higher education. Far from it, the proliferation of university and college campuses resulted from entrepreneurial efforts that included everyone from local chambers of commerce, to city officials, alumni, real estate developers, and state legislators. Most notable, moreover, was the group of Cal State College presidents. In the absence of a formal governing board, the Cal State Presidents assembled themselves into an unofficial executive council that usurped many of the functions of the Division of State Colleges and Teacher Education. This was based on their judgment that the State education bureaucracy, which was directed mainly towards primary and secondary (K-12) education and teacher training, was not attendant to the expanding needs of the state college system. The "mission creep" of the State Colleges, from teacher training to general baccalaureate education, to semi-professional master's degrees, and eventually to the doctorate itself constantly threatened to upset the tri-partite system, and was viewed with great concern by University of California administrators. Nor was entrepreneurial conduct limited to the State Colleges. At the University of California, Los Angeles, the inaugural Dean of Engineering, Llewellyn M. K. Boelter, created a continuing education professional master's degree program to support the booming Southern California aviation industry. These highly specialized, technical master's degrees came to eclipse the college's undergraduate programs and worked to limit the college's emphasis on faculty research; it also served as a model for the Cal State campuses, which began to press for professional master's degrees in new and emerging technical fields.[6]

Nearly all of this is described in careful detail in John Aubrey Douglass' study: 'The California Idea', a historical study of the origins of the California Master Plan (2000). But while Douglass identifies engineering as a "wedge issue" that repeatedly threatened to destabilize the functional differentiation between the Cal State Colleges and the University of California, he does not describe in detail how or why this occurred. While we also do not have the space here to go into this in detail, it is clear that the workforce requirements of Southern California's aviation industry, and later, the defence electronics industries in Northern California (that served as the basis for Silicon Valley), created specialized workforce needs that fuelled the Cal State Colleges' extension into new, advanced degree programs. As exacerbated by a national engineering ‘manpower’ (*sic*) crisis, technical workforce shortages in Southern California had compelled the aviation industry to hire those with but a bachelor’s degree in engineering into increasingly professional and specialized positions. The intense engineering workforce requirements of this one industry, as exacerbated by events such as the Korean War, remade engineering by introducing new patterns of white-collar labour mobility, even as this helped to secure the engineer’s professional standing (Akera, 2010).

We note that a rather broad array of entrepreneurial conduct and market considerations animated higher education policies well before the general circulation of neoliberal ideas. But in the end, it was the established educational bureaucracy that gave shape to the 1960 California Master Plan.

The 1960 Master Plan firmly ensconced the state’s existing tri-partite system. While it affirmed the State College’s right to offer science and engineering master’s degrees, it essentially reserved all doctoral training, except in the field of education, to the University of California system. This is not to say that entrepreneurial conduct did not persist within the revised system. While those within the state colleges felt constrained by the new educational bureaucracy created for the state colleges, within the basic structure set forth by the Master Plan, Clark Kerr developed a subtle system of incentives to compel his campuses to compete with one another to achieve research excellence. Many states, including Texas, would adopt elements of the system of incentives developed by Kerr. The outcome attests to the efficacy of this approach to higher education governance: six out of the ten University of California campuses rank among the top 50 US universities today; three rank within the top fifteen universities in the Shanghai ranking of world universities.[7]

The Select Committee on Higher Education in Texas[8]

In contrast to the California Master Plan, the architect of the new system for higher education in Texas was a committee comprised of one higher education bureaucrat, five politicians, and thirteen political appointees. Among the appointees was a university president, several lawyers, businessmen (and one businesswoman), and a former deputy director of the US Central Intelligence Agency. The chairs of the House Higher Education Committee and the Senate Education Committee also sat on the committee. Chairing the committee was Larry Temple, the chair of the Coordinating Board, Texas College and University System, a controversial appointment given that his own committee was arguably the body under scrutiny.[9]

Texas’ Select Committee on Higher Education (SCOHE) also owed its origins to shifting economic circumstances, demographic changes, and a fiscal crisis. Like California, Texas got its start as a natural resources dependent state. However, by 1970, agricultural industrialization had already remade Texas into an urban population. Although peak oil struck Texas in 1972, as an oil producing state the OPEC oil crisis generated an economic boom, leaving the state’s treasury awash with cash. Texas’ fiscal golden years also occurred during the very period that the baby boomers were entering college. Moreover, given that Texas' economy was booming at a time when the rest of the nation was suffering from "stagflation," Texas experienced its own demographic explosion, one that accentuated the pattern of Southern migration that had already begun by the 1970s.[10]

As contrasted against the constrained growth of the higher education system in California, Texas was one state that permitted the largely unconstrained growth of its higher education system. Local boosters and legislators pushed through legislation to create new campuses as educational access became a major selling point among real estate developers. As a result, by 1983 Texas had 37 separate public institutions for higher education as overseen by 15 separate governing boards. There were six separate university systems, three of which were organized on a regional basis. While college attendance was among the highest in the nation – when tuition and fees were both included, students in Texas paid less than those in California – so long as college expansion was tied to real estate speculation, the results were predictable. The state ranked 46th out of 50 in the SATs (Scholastic Aptitude Test, or the main, standardized test used for college admissions in the US). While the Coordinating Board was set up in 1965 to prevent such an outcome, the Board itself emerged as just another site for political logrolling. Despite the seeming conflict of interest, Temple was among the foremost advocates for reform.[11]

Texas' fiscal situation changed drastically in 1983 with the collapse of OPEC. As a "tax free" state, Texas had no individual or corporate income taxes; given the reliance, as a consequence, on excise taxes, the state lacked the diversified tax base with which to cushion the blow of declining oil prices. During the 1983 session, the state legislature considered a 26% reduction in the state university budget. While the crisis was averted through a 200% increase in tuition (but still just $12/credit hour), the threat of campus closures, further projected budget shortfalls, and the reality of under-utilized facilities—in the most egregious case, campus enrolment hovered at just 1/3 of the predicted enrolment—provided the impetus to conduct an investigation.[12]

Given that all this occurred during the heart of the Reagan-Thatcher era, we might wonder to what extent neoliberal values and policies found explicit entry into the course of events. Certainly, there was a good deal of entrepreneurialism associated with the build-up of Texas' higher education institutions. But in a manner not so different from the developments in California, most of what preceded the Select Committee's work was, at best, an older form of market liberalism, and at worst, and even older form of interest politics. This being said, it will be evident that the existence of strong market traditions in Texas, and their integration with the political traditions of the state, provided fertile ground for the spread of neoliberal ideas and practice.

Neoliberalism entered the Select Committee's conversations through at least two identifiable paths. The first was Austin's successful bid to bring the Microelectronics and Computer Technology Corporation (MCC) to Texas. The state worked hard to attract the nation's first research consortium, created in response to the US crisis in "national competitiveness," competing with other better known cities and regions such as Atlanta and the North Carolina Research Triangle. In fact, the entire state became struck with high-tech fervour not unlike the speculative excesses found in the state's deep historical engagement with oil. Riding on the crest of this development, and rather eager to avoid a critical investigation that might damage the reputation of the state's higher education system, Texas Governor Mark White instructed the Select Committee to focus on reshaping the state's public universities to support this new high-tech economy instead of focusing too much on costs and campus closures. In the back of his mind was the fact that the populist political figure, Ross Perot, had just spearheaded a critical study of the state's primary and secondary education system. In any event, it was White's vision that the state's public universities would produce the educated minds that would become "the oil and gas" of Texas' future.[13]

Other elements of an emergent, neoliberal discourse entered the Select Committee's policy deliberations, as it did in many other policy arenas during the era of Reaganomics. However, the other principal path through which neoliberal ideas entered directly into the committee's deliberations was through the two members who were enmeshed in this national policy conversation. One was Adm. Bobby Ray Inman (Ret.), former Director of the National Security Agency, Deputy Director of the CIA, and now CEO of MCC. The other was the university president on the committee, Rice University President, Norman Hackerman. Hackerman was a well-known chemist and member of the National Academy of Sciences, and hence another Washington insider. Interpreting the Governor's charge in predictably instrumental ways, these two individuals began sketching out a highly incentivized, market-oriented solution for expanding the state's capacity to perform basic and applied research of value to new and emerging technological industries. Their plan called for creating a miniature version of the National Science Foundation (NSF) within Texas, and directing this body to the economic interests of the state.

As it turns out, Texas was already spending a considerable sum on research. However, it did so through a bureaucratized approach to appropriations that made the funds an institutional entitlement, based on annual allocations from a special fund controlled by legislative interests and politics. Inman and Hackerman worked to shift the discourse from that of entitlement to investment with the explicit promise of a return on investments. Specifically, they asked the state to set aside an amount equal to 10% of a 3-year running average of the amount of sponsored research paid for by the federal government in the state, and to allocate this to basic research in emerging technological arenas of interest to the state. The idea was to leverage state funds to capture the larger sums associated with federally sponsored research, which in turn would provide the foundation for setting up new industries in Texas. For many of the business-oriented members of the committee, their quick uptake of the idea was a natural, or rather, naturalized extension of their own, existing orientation towards speculation and investment. Inman and Hackerman's proposal clearly built on a familiar language with which the many business-oriented members of the Select Committee could engage. On the other hand, in a curious hybrid that merged commercial traditions with academic ones, the task force charged with working out this new Texas Research System sought to create competition among researchers in and across specific universities using an NSF-style peer review process. Along with a number of other provisions, this was a system designed to slowly wrest the control over the state's research spending out of the hands of interest politics, which by definition favoured established industries versus new high-tech industries.[14]

While research was one focal point for the Select Committee's actions, educational access also emerged as an important issue. During the committee's very first meeting, and in response to the conversation about state subsidies for research, the Chair of the House Committee on Higher Education, Wilhelmina Delco (an African-American legislator from the liberal and urban political environment of Austin) indicated that she did not want the focus on excellence to occur at the expense of the poorest residents of the state. This was also a time when Mexican Americans were beginning to find greater political representation within the state. One of the reasons for the regional organization of the state university systems was to ensure that adequate resources were given to the educational needs of the state's growing Hispanic population. (Texas would become a majority minority state in the first decade of the 21st Century.) As it turns out, Inman also emerged as one of the most vocal advocates for access. If the goal of high tech expansion was to sustain the State's desire for economic expansion and population growth (which in policy documents was in fact conflated with economic growth), it made little sense to build an educational system that served only the elite. It needed to be a diverse system capable of producing a fully diverse and skilled workforce needed for a high tech economy.[15]

Internal differences of this sort, along with the influence of one of the powerful, conservative legislative representatives on the committee, would limit the Select Committee's ability to thoroughly reshape Texas high education. The Texas Charter for Public Higher Education accomplished some of the Select Committee's stated aims, especially through the expanded authority given to the renamed Texas Higher Education Coordinating Board (THECB). Nevertheless, this outcome also indicates the limits of a voluntary body. At one point, the Select Committee raised the possibility of inviting someone from California to speak about how they had structured their system via the 1960 California Master Plan. However, in so far as the committee divided its work into separate task forces, the group that focused on governance failed to see how one of the major benefits of California's tri-partite system was that it concentrated state research monies within a specific segment of its higher education system. As contrasted against the frankly blunt system of incentives established under the proposed Texas Research System, Clark Kerr had developed a much more subtle system of incentives as administered by a sophisticated higher education bureaucracy in ways that placed its campuses in more direct competition with one another. Without a strong system of higher education and its experienced bureaucrats, Texas was simply unable to see other ways to structure state higher education policies.[16]

Still, we should be careful not to judge the outcomes too hastily. As a result of the high-tech boosterism of which the Select Committee's efforts were a part, the city of Austin, Texas stands today as a high-tech mecca second only to Silicon Valley. While Texas failed to develop an extensive network of strong research universities outside of the health sciences where it had historic strengths, given the competitive posture of US universities, it's not clear that it would have been wise for Texas to attempt to do in the 1980s what California accomplished in the 1960s. The University of Texas-Austin, which had a rather modest reputation three decades ago, now stands among the top 20 public universities in the United States; it stands at #10 among all US engineering schools.[17]

COMPARATIVE ANALYSIS AND AN INTERPRETATIVE FRAMEWORK

From these case studies, we extract the following observations, which we then use to analyse the more recent developments in Europe and Denmark:

- *Entrepreneurialism* – Entrepreneurialism clearly has been an important part of the institutional changes in higher education. While neoliberalism may have accentuated certain aspects of entrepreneurial conduct, such as the rhetorical use of an investment metaphor, entrepreneurial conduct was already deeply rooted within US higher education well before the spread of neoliberal ideology. This was true not only in California, but during the period of speculative expansion in Texas' higher education system.
- *Governance* – Educational bureaucracies at the state level have served as a vehicle for both defining and constraining the expansion of higher education institutions, although their efficacy apparently varies from state to state. Very different political and bureaucratic processes can shape key aspects of higher education within a state, and the capacity to develop sound policies appears to depend on the strength of the existing education bureaucracies.
- *Neoliberal Influence* – In the face of these two observations, we need to be attentive to the specific ways in which neoliberal economic doctrines influenced the conduct of both state and private actors. The devolution of federal authority for economic planning down to the states, increased reliance on public-private partnerships for both decision-making and research, increased reliance on competition, and new mechanisms for accountability all found specific expression within the Select Committee's work and its recommendations. We note, nevertheless, that what we end up with are institutional hybrids, as when the practice of peer review became the chosen method for fostering increased competition among Texas' research universities.
- *Geography* – Geography was another important factor in these two case studies, both in terms of the differences across the states, but also with regards to regional differences within each state. In both cases, regional differences created different patterns of demand for engineering and technical talent, even

as it constituted the political fabric upon which to carry out conversations about educational reform.

- *Demography and Access* – So long as public education is viewed as a means of attaining individual as well as collective economic ends, access will surface in political conversations about higher education reform. Demographic growth also strengthens the call for access. Given the opportunities and the substantial state investment in higher education, certain segments of the state bureaucracy will nevertheless join private interests in aligning state investments in higher education with the economic goals of the state. Such alignment is not unique to the era of neoliberalism, although the emphasis it receives may be amplified by it. Meanwhile, elite research universities, such as the University of California system in the first case study, may place research and other institutional goals above that of access.

With these observations in mind, we now turn to what we saw and heard about the Bologna Process and the associated changes in Danish engineering education, especially at the level of Danish national policies.

THE BOLOGNA PROCESS AND THE DANISH NATIONAL RESPONSE

The Bologna Process was initiated in 1999 through a meeting of the education ministers of 29 European countries. While expectations of professional labour mobility accompanied the Treaty of Maastricht, given the financial and monetary-policy orientation of early conversations about European integration, there was no strong focus on higher education and workforce development in these early discussions. The main concern behind Bologna was that European universities, despite the reputation of their leading institutions, were not producing the quantity and quality of graduates necessary to succeed in the global economy.

It is clear that a neoliberal policy environment undergirded the Bologna Process, much in the way that a broad context for neoliberal thought influenced the deliberations of the Select Committee in Texas. Building on two decades of conversation about national competitiveness, a basic decision was made to place European higher education institutions in competition with one another by creating a single higher educational market. This was accomplished by defining a European Higher Education Area built around a 2-cycle degree program consisting nominally of 3+2 years of study. But while the early focus was on the mobility of students between the two cycles – the Diplom. (bachelor's) and Candidate's (master's) degrees and their equivalent – the process has generated interesting secondary phenomena. Perhaps most notable of these additional changes has been the emergence of more specialized degree programs at the Candidate's level as made possible through the broader European-wide market for students (Adelman, 2009). Incorporation of the Lisbon Strategy in 2000, with its focus on research and innovation, has also expanded the scope of the Bologna Process to include third-cycle (PhD programs) and short-cycle (vocational) educational programs (Keeling, 2006).

Geography also influenced the Bologna Process. Given the diversity and varying strengths of Europe's educational systems, the education ministers were unwilling from the outset to unify their degree programs through a uniform accreditation standard. Although the ministers did agree to standardize the basic degree programs structure across Europe (although variations persist), beyond this they agreed only to "harmonize" their degree programs through greater transparency and accountability. In a clear draw on neoliberalism and its frequent emphasis on accounting and accountability, the European Credit Transfer System (ECTS) – a system originally designed to facilitate student transfers and study abroad agreements – was remade into a system that offered detailed measures of what was taught in each degree program. This was accompanied by a standardized assessment and "quality assurance" regime designed to guarantee stated learning outcomes, but as implemented through accreditation bodies in each of the member states. In addition to serving as a measure of earned credits, or "accumulation," ECTS currently also serves as a proxy for faculty responsibilities and effort.

For US observers, it will be interesting to note that this means Europe has embraced a learning outcomes and assessment regime far more extensive than anything required under ABET's EC 2000 accreditation criteria.[18] This is the mechanism that has begun to form a single higher education market in Europe, as opposed to an accreditation regime designed simply to enforce minimum standards. Interestingly, the current conversations surrounding changes in ABET accreditation criteria point to the frustrations within the United States with regards to enabling educational innovation and variation under an accreditation regime (Flaherty, 2015).

The Bologna Process was preceded by decades of attempts from European Engineering organizations and the EU commission to establish a content-based framework of mutual acceptance and recognition. This had included stringent criteria defining the curricula elements, admission criteria, and lengths of study to be common for the EU. As an early outcome of this, a European system for individual accreditation of engineers was established with the 'Europe Engineer' certificate administered by the Engineering Association in the individual countries, but this only turned out to be successful with civil engineering. One of the obstacles to this attempt was the difference between the British individual certification of engineers based on examining trained engineers from Polytechnics and universities after some years of practice, and the system in continental Europe, which accepted engineering degrees as sufficient evidence of professionalism.

Political economic differences and market position have also influenced how the Bologna Process has unfolded across Europe. A biennial self-assessment conducted under the Bologna Process since 2005 has demonstrated that there has been substantial variation in how quickly the ten "action lines" (action items) defined over the course of three key ministerial meetings between 1999 and 2003 were picked up by the different EU countries (Terry, 2008). Taking the 2005 data as an indication of early adoption, Scandinavian countries were among those that moved most quickly towards implementation, most likely because of their strong, social democratic traditions for governance. Joined by other smaller countries located in Europe's periphery, the Scandinavian countries took advantage of the opportunities afforded by the coordinated market to create more advanced, specialized degrees, many of which are pegged to new and emerging high-tech industries. By contrast, the largest countries and their leading research universities have had less reason to embrace Bologna. As such France, Germany, and England have been among the late adopters.[19] On the other hand, different segments within each country experienced Bologna differently. For example, the German Fachhochschulen have been successful in using the Bologna Process to extend industry-oriented, advanced vocational training to the Candidate's level. By contrast, political processes have made this extension difficult in Denmark, forcing its engineering colleges to seek a variety of other strategies for their institutional survival.[20]

We should also note that a more critical study, "Bologna with Student Eyes," assembled by the European Students' Union (ESU) in 2007, documents how institutions have been selective and opportunistic in their implementation of Bologna in ways that the official metrics do not capture.[21] While the ESU report may itself be partisan in some respects, especially with regards to its emphasis on access, this is a key point to consider. From the point of view of a multi-scale, multi-site study on the institutional responses to Bologna, it remains important to document variation as well as conformance, both at the EU and national levels. Especially in the context of new policies favouring an "innovation economy," it is precisely the institutional variation and specialization made possible through "harmonization" – not the full standardization of educational systems – that policymakers want to see. Using Denmark as a case study with which to document a national-level response to Bologna was precisely the core objective of our field work.

Denmark, along with the other Scandinavian countries' responses to Bologna is unique because of their liberal political culture and the attendant emphasis on educational access and social mobility. While at the time of our visit there were student protests surrounding planned reductions in government subsidies for their studies, historically Denmark has spent a rather large portion of its wealth on public education. Based on 2009 World Bank data, Denmark spent 8.7% of its GDP on public education, as contrasted against the rates in Germany (5.1%), France (5.9%), United Kingdom (5.5%), and the United States (5.2%). Denmark also spends more than Sweden (7.3%) and Norway (7.2%).[22] (More recent data were available for other countries, but not for Denmark.) In a manner unfathomable to those of us in the United States, students receive stipends simply for attending college. Denmark's Gini coefficient, a standard measure of national income inequality, while no doubt buoyed by restrictive immigration policies, stands at 24.8, as compared to 27.0 for Germany, 32.3 for the United Kingdom, and 45.0 for the United States.[23]

Similar in some ways to the immediate post-war period in California, this basic commitment to public education and a balanced class structure have shaped the

Danish national response to Bologna, although not without definite neoliberal elements. Indeed, concurrent to the post-war expansion in California, the Danish government established the Technician Commission in 1950 to suggest initiatives that could meet the growing need for skilled technicians and engineers during the post-war period. The focus of the commission was on the supply of relevant manpower to industry and the expansion of the capacity of engineering schools. The Engineering Academy was established to train engineers for industry without tapping into the recruitment of students with vocational backgrounds who were seen as still needed in industry (For further background see Jørgensen, 2007).

It is our understanding that the concrete manifestation of the more recent policy directions in Denmark has been a series of actions and government decisions. The most significant of these were the establishment of a national Globalisation Council in April 2005, the government's adoption of a national globalization strategy in the policy document: "Progress, Innovation and Cohesion" (The Danish Government, 2006), and Parliamentary Law No. 562 passed by the Danish Parliament. This was an Act designed to merge the nation's 150 specialized semi-professional colleges into a new system of eight regional University Colleges. This was done for the purpose of simultaneously expanding educational access, controlling costs, and upholding the status of "medium cycle," or three-year, occupationally-oriented bachelor's degrees. While PL 562 affected primarily these Diploma (baccalaureate) institutions, because of an initial decision to fold the nation's engineering colleges (Teknika) into the University College system, this has had complex implications for all engineering degree programs and institutions.

The tension between neoliberal policies favouring a rational restructuring of Danish higher education and its efficient integration with global economic priorities; and social welfare principles designed to extend educational access are also evident in Denmark's initial response to the Bologna Process. On the one hand, strong central government traditions enabled Denmark to quickly and efficiently embrace the 1999 Bologna Declaration. However, rapid adoption also contributed to a kind of policy failure. The initial vision for the Bologna Process led some to hope that the 3+2 structure would enable the government to off-load some of the costs of the higher, Candidate's degree to corporate sponsors willing to pay for employees' specialized training in their desired areas. Across Europe – with perhaps some exception in England – there has been opposition to such a shift. Danish per-capita expenditures in higher education in any case has remained one of the highest, if not the highest, among EU countries. This has only increased the Education Ministry's resolve to find efficient solutions that ensure that societal and economic benefits accrue from this tremendous public investment in higher education (Schjær-Jakobsen, 2010). At a more general level, and in a manner analogous to the US case studies, these new policy initiatives in Denmark have sought to bring about a better articulation of the role of the public sector in producing the workforce needed for an era of purportedly intensified economic growth and competition.

Whether or not technology is changing faster than in prior decades, it is important to take note of Denmark's technological sectors and how they have shaped national conversations about workforce development. Denmark has had considerable strengths in a number of sectors, including electronics, medical technologies, and mobile communications. While some sectors, such as mobile communications, have recently faltered, other arenas, especially alternative energy, global transportation and trade, and energy distribution systems have experienced resurgence amidst new concerns about sustainability and energy self-reliance. Selected segments within some of Denmark's older industries, such as the new work on bio-fuels that grew out of Denmark's strengths in agricultural technology and food processing, have also made a high tech turn. What we saw and heard during our visits indicated that these and other market segments somewhat more remote from engineering, such as those built around design, have buoyed the Danish economy, fueling hopes for an "innovation economy." Meanwhile, a number of more traditional industries, especially international trade and manufacturing in Jutland, have provided a constant baseline of demand for a sizable Danish engineering workforce. This stable demand for engineering talent has, for many institutions, provided the tuition resources necessary to underwrite new degree programs and initiatives in engineering education. An engineering workforce shortage of about 8,000 engineers was anticipated in the coming decade at the time of our visit.

As compiled from our interview data, we regard the primary response of the Danish government to the current mix of opportunities and challenges presented by European integration and the Bologna Process to be as follows:

- A decision to embrace the Bologna Process through a desire to introduce market competition, greater specialization, and responsiveness within Danish educational institutions, especially at the master's level.
- A decision to address both the (a) short term recessionary softening of the labour market and the (b) long-term competitiveness of the Danish workforce by having 50% of all high school graduates continue on to Baccalaureate-level instruction (B.Eng. or B.Sc.), and for 50% of these to obtain the more advanced Candidate's degree (M.Sc.).
- Simultaneously, an attempt to contain the costs of higher education through rationalization, both through the legislatively mandated consolidation of the nation's semi-professional schools into a single University College system, and through fiscal policies designed to force similar administrative restructuring within the nation's universities. Many not-for-profit research institutes that were supported through public funds were also absorbed into the nation's universities.

Taken as a whole, these state actions indicate broad alignment with neoliberal ideology, and especially with regards to the adaptive—and adoptive—character of neoliberalism, where market principles and conduct become embedded within state and public bureaucracies, even as other agendas, especially social mobility and access, remain foregrounded in certain respects. The market orientation of the state's overall policy intent was also evident in the effort underway at the time of our visit to define an "innovation" agenda that would determine how national research funding would be allocated to the universities. This report was issued shortly after our visit, in December of 2012, under the title, "Denmark—a Nation of Solutions." This policy document is clearly framed as a response to the 2008 market collapse, which resulted in an actual 8% decline in Denmark's GDP. Its text also belies a latent fear about the fragility of a small, Scandinavian country's economy. The report clearly espouses the view that it is the government's role to ensure that public investments in research, innovation, and education translate into economic growth and job creation. It recognizes the challenges of a country dominated by small and medium enterprises, and calls for strategic public investments to develop new market niches like sustainability and new energy systems where Danish industry has distinct advantages. More generally, the report calls for a more integrated and, again, rationalized system for the public financing of research. Reminiscent of the efforts in Texas, the basic outlines of the proposed system reveal the maturation of the kind of dialogue initiated by the Select Committee in Texas, and seeks in a much more controlled way to ensure that state investments in research becomes an effective strategy for market development. We should note that such policies extend further the conflation between the roles of public higher education and the demands of the marketplace (Danish Government, 2012).

Finally, there are a number of additional factors constituting the broader societal context for the present reforms in Danish engineering education. Not all of which relate to market interests or Danish national government policies. These factors all appeared to shape the responses of the universities and engineering colleges that we visited, and very closely mirror the issues that we identified as being important in the US case studies:

- Geographic factors having to do with the fact that Denmark has one major metropolitan centre (Copenhagen), and a large rural-industrial periphery (Jutland).
- A history of relatively limited labour (and student) mobility, which has created distinct regional markets for engineering education. (This contributed, for instance, to Aalborg University's decision to open a new campus in Copenhagen.)
- Conversely, increasing labour mobility among engineering educators as a result of the European Higher Education Area, and the resulting faculty recruitment and retention challenges for Danish universities vis-à-vis their larger European counterparts (especially German universities).
- Social democratic commitments to relatively open enrolments within the public university system, which when paired with high matriculation targets for college enrolment, limited mobility, and a rigid system of enrolment based budgeting, severely limits selectivity within Danish universities.

CONCLUSION

This description of the major policy directions, first in US higher education, and then in European and Danish higher education points to a shifting policy landscape, one characterized by increasingly neoliberal modes of governance. This includes increasing market competition; a strong focus on workforce generation; attempts to rationalize higher education administration through new measures of accountability; and various efforts to align higher education and research to state and national agendas. For Denmark, the present emphasis is on a national "innovation agenda" designed to sustain Denmark's position within an increasingly competitive, global economy. While it remains tempting to measure neoliberalism through its specific characteristics, what is again more fundamental is the general, underlying penetration of market values and practices into the institution of public higher education. There has clearly been a realignment of Danish and European higher education, as well as the systems in the United States, to more closely match up with commercial interests, metrics, and practices.

This being said, the diverse political economic contexts for higher education ensured that there were continuous efforts to balance economic interests with other socially-oriented policy objectives, such as educational access, social mobility, and the basic structure of a regional or national workforce. This is a central feature of public conversations about higher education that spanned both space and time. If Denmark's actions are unique in the context of Europe, it is because it was among the set of smaller, peripheral states that embraced the Bologna Process more eagerly, even as its social democratic foundations helped to maintain certain non-market objectives in the foreground.

Focusing on the present, our visit to Denmark made it quite evident that Europe is in the process of thoroughly reworking its system of higher education. From the standpoint of a pair of US observers, the most striking thing is that Europe seems to be capitalizing on the strengths of its secondary education system to elevate their former, typically, five-year undergraduate degree programs into a set of terminal master's degrees. Restated from the point of view of one of the perennial concerns of engineering educators in the United States, Europe has taken definite steps towards making a Master's degree the first professional degree in Engineering. This has been an elusive goal in the United States, most likely because of a national commitment to educational access via its state universities and especially its land grant institutions. Moreover, the Master's degree remains an orphaned degree in the United States, in that it is often considered a stepping stone for those pursuing a PhD (or worse, a soft landing for those who fail to obtain the PhD). In Europe these degrees are, it appears, being refashioned into specialized technical degrees that are tailored to the demands of the new innovation economy. While the United States has traditionally led Europe in college attendance, especially when junior colleges and community colleges are included in the statistics, Europe may well surpass the United States in the production of students with specialized master's degrees, if Denmark's present policies prove to be a bell-weather.

Some of the other similarities and differences between the US and European/Danish developments deserve further comment. From the standpoint of governance, it's clear that strong central governments and educational bureaucracies, as was found in California as a whole, contribute to the rapid and intentional transformation of higher education. On the other hand Europe as a whole has faced a specific challenge in the autonomy of its separate states and its multiple systems of higher education (not unlike the situation in Texas). Still, the extension of neoliberalism, with its unifying ideology and transnational reach, has provided not only the motivation, but the discursive forms and bureaucratic practices necessary to unfurl a fairly uniform policy framework in Europe, one with sufficient consistency to create the beginnings of a common market for higher education. In this respect, it is the United States that faces larger challenges. With fifty separate state systems for higher education and a national constitution that leaves most of the authority for public higher education to the states, the US as a whole lacks the governance structures needed to initiate a coordinated response to the developments in Europe.

What stands at the core of the Bologna Process is in fact a new combination of state actions and entrepreneurial and market-based responses—a clear "redeployment" in the relations between the market and the state. Amidst the complex ecology of higher education institutions in Europe, the Bologna Process has produced a flexible and "agile" approach to institutional change, one based on diverse responses whose mettle is currently being tested in the global marketplace for ideas. While we see some of this diversity at the European level, crucial to a full understanding of the Bologna Process' impact is a look at the institutional variation that also exists within specific countries, such as Denmark. Indeed, to truly assess the scope of neoliberalism's influence, we need detailed, institutional level data to observe how (and whether) entrepreneurial behavior and other forms of market-oriented practices are extending down into individual educational institutions and their faculties. This too was a focus for our site visits, the findings of which we report in the chapter that follows.

NOTES

1. Our discussion of the California Master Plan, while based partly on original research, draws heavily on prior work by John Aubrey Douglass (2000); See also California State Department of Education (1960); and Texas State Legislature (1987).
2. On Kerr's own views of his efforts, see Kerr (1964).
3. For a review of the literature, see Hilgers (2010) and Hilgers (2012).
4. US Census Bureau, *Population Estimates, Historical Data*. Accessed 10 September 2015 at: https://www.census.gov/popest/data/-historical/. On the general post-war expansion of California's economy, and its defence sector in particular, see Roger Lotchin (1992).
5. In Douglas (2000) the Strayer Report is described on pp. 184–194; while the Restudy is described on pp. 213–219. The legislature occasionally overrode the bureaucrats' recommendations; nevertheless the agreements that emerged out of the Report limited the spread of new campuses.

[6] The entrepreneurial conduct of the State College Presidents is captured in Douglass (2000) and is further explored in a paper by one of this chapter's authors in Atsushi Akera (2010). On Boelter and UCLA, see Akera (2012).

[7] *A Master Plan for Higher Education in California;* Douglass (2000:265–297); The rankings may be found in 'US News and World Report', accessed 12 August 2015 at: http://colleges.usnews.rankingsandreviews.com/bestcolleges/rankings/national-universities/data and Shanghai Rankings accessed 12 August 2015 at: http://www.shanghairanking.com/ARWU2014.html

[8] An extended version of this story may be found in Atsushi Akera, "The Neoliberal Transformation of the Texas System of Higher Education: The Select Committee on Higher Education (SCOHE, 1985–1987)," Conference paper, SHOT Annual Meeting (October 2014), Dearborn, MI. Unpublished manuscript in the author's possession, available upon request.

[9] Clay Robison, "Committee Chairman Low Key and Doesn't Stray from Target," *Houston Chronicle* (29 September 1985), n.p. In RG 100, AC 1989/76, Select Committee on Higher Education Records, Box 3/1. Texas State Archives, Austin. Tex.

[10] Texas' population rose from 9.6 million (1960) to 11.2 million (1970, +16.9%), to 14.2 million (1980, +27.1%), and was the third largest state at the time of the study, behind California and New York. Office of the Governor, Texas 2000 Project, *Texas Past and Future: A Survey* (June 1981), 4. CoE Records, Box CDL3-A14. UT Archives, Austin, Tex.

[11] Transcript, Select Committee, Council on Higher Education, 14 October 1985, Tape 1, Side 2, 1. RG 100, AC 1989/76, Box 1/1; "Texas Ranks…," RG 100, AC 1989/76, Box 2/17. Texas State Archives.

[12] Laylan Copelin, "Higher Education Panel to Diagnose Ills in $6 Billion College System," *Austin American Statesman* (13 October 1985), B8. In RG 100, AC 1989/76, Box 3/1; Scott Bennet, "Thy Will be Done," *Texas Business* (June 1985), n.p. In RG 100, AC 1989/76, box 2/17. Texas State Archives.

[13] Gov. Mark White, Opening Address. Select Committee on Higher Education, Meeting Transcript, 14 October 1985. SCOHE Records, Box 1, Folder 1. Texas State Archives; See also Office of the Governor, *Texas Past and Future*. On MCC, see "MCC: Keeping the Promise?" special issue, *Texas Technologies* 1/3 (November 1985). RG 100, AC 1989/76, Box 2/19. Texas State Archives.

[14] "Proposed Texas Research System," 1 August 1986. RG 100, AC 1989/76, Box 1/13. Texas State Archives.

[15] SCHOE Transcript, 14 October 1985, Tape 2, Side 1, 7f. RG 100, AC 1989/76, Box 1/1; Gary Scharrer, "Hispanics will Monitor School Panel," *El Paso Times* (30 October 1985), n.p; and "Inman Has a Point," *Ft. Worth Star Telegram* (9 October 1985), n.p. Both in RG 100, AC 1989/76, Box 3/1. Texas State Archives; Texas Higher Education Coordinating Board, *Closing the Gaps: The Texas Higher Education Plan* (2000), online report, 8. Available at http://www.thecb.state.tx.us/reports/PDF/0379.PDF?CFID=31731231&CFTOKEN=30161270 (Accessed 13 September 2015).

[16] SCHOE Transcript, 31 October 1985, p. 26. RG 100, AC 1989/76, Box 1/2; Carl Parker to members, Select Committee, 21 November 1986. RG 100, AC 1992/299, Box 7/SCOHE Correspondence from Members. Incomplete records of the task force's deliberations may be found in "Task Force Meeting Minutes." RG 100, AC 1989/76, Box 1, Folders 11–13. All in Texas State Archives. See also, *Texas Charter for Public Higher Education.*

[17] See http://colleges.usnews.rankingsandreviews.com/best-colleges/rankings/national-universities/top-public; and http://colleges.usnews.rankingsandreviews.com/best-colleges/rankings/engineering-doctorate (Accessed 15 August 2015).

[18] U.S. educational policy analysts began noticing this fact around 2008–2009. See especially Adelman (2009), xviii–xix. See also Keeling (2006), 208–209; and Terry (2008), 123.

[19] The 2005 report may be found at: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/BPStocktaking9May2005.pdf; subsequent reports, issued in 2007, 2009, 2010, and 2012 may be found through the EHEA online archives, http://archive.ehea.info (Accessed 23 June 2014).

[20] This point is explored further in our other contribution to this volume (Chapter 3). See Juan Lucena et al. (2008:439).

[21] European Students Information Board, *Bologna with Students Eyes* (London: ESIB, 2007), at: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/Bolognastudenteyes2007.pdf (Accessed 23 June 2014). Cited in Terry (2008:206f).

[22] http://data.worldbank.org/indicator/SE.XPD.TOTL.GD.ZS (Accessed 23 June 2014).

[23] CIA, "Distribution of Family Income-Gini Index," *The World Factbook.* Available at http://data.worldbank.org/indicator/SI.POV.GINI/ (Accessed 23 June 2014).

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3. INSTITUTIONAL RESPONSES TO THE BOLOGNA PROCESS IN DANISH ENGINEERING EDUCATION

INTRODUCTION

The aim in this chapter is to present and discuss our detailed, empirical findings with regards to the institutional-level responses to the Bologna Process among Danish engineering schools and universities. It also documents their responses to new Danish national policies as they relate, both directly and indirectly, to the Bologna Process. The responses that we document reveal a good deal of institutional variation and institution-specific conduct with regards to such things as entrepreneurialism, educational philosophy, pedagogy, curricular content, commitments to research, and the posture each institution adopted vis-à-vis other institutions with which they perceived themselves to be in competition. While this account makes it clear that neoliberalism and an increased focus on market oriented behaviour have permeated Danish engineering schools, the scope of this shift requires careful scrutiny before we can claim that there has been a general neoliberal reorientation within these institutions. We carry out this analysis in this chapter.

Our analysis is built upon a multi-site, multi-scale research design, in that the point of our study is not to just document whether senior university administrators embraced neoliberal polices, but whether neoliberal practices permeated academic organizations down to the departmental level, including the conduct of individual faculty members—and ideally, students. We are interested in documenting the extent to which neoliberalism finds specific expression as a result of the practical implementation of the Bologna Process.

We expect that this review of our findings will reveal mixed results. Given the strong social democratic traditions in Denmark, and well-established political processes and structures for higher education policy making, we expect that the institutional conduct will be a mixture of neoliberal and more traditional governance practices. Such a mixture would still constitute a redeployment between state and private responsibilities. Moreover, this mixture might itself produce institutional diversity in a way that conforms to the more basic, neoliberal intent of fostering institutional competition. This being said, the question of whether the reforms are truly neoliberal in character depends on the extent of the syntagmatic extension of neoliberal practices into the daily conduct of Danish higher education. This analytic assessment will be conducted in the final part of this chapter.

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The chapter itself has a straightforward organization. It begins with a brief presentation of our research design, describes an important development that occurred at a level in between that of national policy and individual institutions, and then provides the detailed responses of the four institutions that we visited. These institutions are Aalborg University (AAU), Aarhus University (which had already absorbed the IHA, making it their baccalaureate institution for engineering), IHK (the engineering school of Copenhagen which at the time of our visit was still separate from DTU), and the Technical University of Denmark (DTU). We then provide some initial insights into faculty perspectives on perceived changes before closing with our overall analysis and conclusion.

STUDY DESIGN AND METHODOLOGY

Our study was fashioned in the manner of a US external program review. This approach seemed well suited to a study of specific institutions. The study was conducted as a series of site visits, with pre-prepared interview questions, to four Danish universities and engineering colleges that offered engineering degree programs. To ensure alignment with PROCEED's objective of supplying a grounded description of institutional change processes, we designed the study as a multi-site, multi-scale study, in which interviews were held with department heads and study board directors, as well as members of the administration. Interviews of administrators extended up to the level of the dean of engineering, or the rektor in the case of the engineering colleges.

A total of 17 interviews, typically 60–90 minutes in length, were held at the four established engineering institutions in Denmark (at five general campus locations) that were geographically dispersed across the different economic regions within Denmark. Between three and seven interviews were held at each site. For each interview, the lead investigators (the authors of this chapter) were accompanied by one of the Danish researchers from the PROCEED project, both to provide language assistance, supply contextual information, and pose additional questions where appropriate. This was done to ensure that our study benefited from, and remained integrated with the other work and broader objectives of PROCEED. Nevertheless, we felt that modelling our work after an external program review, especially as carried out by a pair of international observers, would help create an objective distance that would elicit more candid responses. Beyond these agreed upon parameters, both subject and site selection were left in the hands of the PROCEED staff members, in a manner generally consistent with US external program review practices. Our intentions with regards to a multi-scale survey design were not fully realized; we had hoped to speak with general members of the faculty, as well as students enrolled in degree programs, but our institutional hosts continued to feel that we might gain more information from speaking with those occupying responsible positions. As such, our data sample has a "top-heavy" bias.

Our overall research question had to do with the probable infusion of entrepreneurial values and neoliberal practices into Danish engineering schools and universities. The subsidiary research questions that followed from this overall focus consisted of the following, and facilitated our subsequent interpretation and analysis:

- What knowledge and overall understanding does each subject have about the overall policy context for the current engineering education reform efforts?
- How is this policy context reflected in local initiatives?
- What are the educational reform practices that were used to implement these changes at different levels within each organization?
- What are the relationships that exist within each institution? Across the institutions?
- What changes have there been in terms of faculty, resources, facilities, curriculum, student learning outcomes, and pedagogy that reflect, run independently, or run in contradistinction to the prevailing policy context?
- What resistance has there been to change, and how and why do these manifest themselves?

The general method we employed was that of semi-structured interviews. This was supplemented by general field observations afforded by our site visits, which helped to provide valuable contextual information about regional differences and student demographics.[1] Our interview questions were designed to allow us to triangulate upon our principal research questions by posing broad questions about contextual understanding as well as the subject's current experience.

All interviews were recorded and subject to rough transcription in searchable (digital) form. No formal coding method was employed. Given our focus on neoliberalism, our emphasis has been on interpretation, as opposed to quantitative assessments of change. To support the veracity of our interpretations, all interview data were reviewed twice, first for the purpose of producing individual site visit reports, and later as based on an initial outline of this chapter.

INSTITUTIONAL RESPONSES

We found each of the universities and engineering colleges that we visited to be remaking their institutions in response to a changing policy environment, as well as the opportunities created by newly emerging "high tech" industries. While we describe the individual institutional responses below, there is one response that unfolded on an intermediate scale that requires prior description.

This response had to do with the engineering colleges' reaction to the Danish parliaments legislation establishing the University College system (LBK 215) from 2013. This response also affected the Danish universities. Even prior to this legislation, several other policy decisions had already altered the basic character of the engineering colleges. The first was a mandated change in 1992, when IHA and all other engineering colleges were renamed engineering colleges in place of the title, 'Teknikum' (which conformed to the German model of the 'Fachhochschulen'). This implied that their recruitment base was extended from being vocationally trained craftsmen to include high school graduates. This also made these schools much more like the engineering school adjacent to DTU, the Danish Engineering Academy. Including the formal engineering degree programs offered at places like Aalborg University and DTU, the three different types of engineering education programs were now reduced to two, with a new formal demarcation created between Diploma (B.Eng.) engineers and "academic" engineers (those holding a M.Sc. or Candidate's degree). Under the influence of the Bologna Process, the Diploma degree was then redefined as a 3.5 year bachelor's degree (including a ½ year internship), while the university-based engineering programs, following Bologna's 3+2 format (B.Sc./M.Sc.), introduced a 3-year stopping point, where students could earn a bachelor's degree and move on to employment or another academic institution. The underlying intent of the change for the engineering colleges was to reduce the total costs of education by accelerating the engineers' entry into the workforce. This would also apply to engineering students enrolled at the university who ended their degrees with the B.Sc.

The political intent was for the engineering colleges to be folded into the recently established University College system, which brought together many of what in the U.S. would be referred to as semi-professional schools under a single administrative umbrella. Many were expected to share a common campus, in the name of improved educational opportunities and efficiency. However, at an earlier point in time, the engineering degrees received through a Teknikum had been granted official sanction as full professional degrees. Given that the University Colleges were set up for semi-professional degree programs, and the professional interests involved, the engineering colleges uniformly opposed the new legislation, proposing instead to align themselves with the nation's research universities. It was said that, in their view, this "would be [kind of a] devaluation of the semi-academic standing of engineering lumping it together with nurses and teachers" (PROCEED researcher). It was also suggested to us that the engineering colleges were also interested in being a player in the new "innovation economy," and that they felt that alignment with the universities would give them access to national research monies. In either case, this shift in focus was subsequently sanctioned by official changes in policy that gave the engineering colleges until 2014 to merge with one of the nation's universities. The reason the universities were willing to accept such an arrangement is discussed in the context of the individual institutional responses described below.[2]

We now turn to the specific institutional responses, beginning with a brief summary of the history of each institution, their respective challenges, and then the principal strategic actions undertaken by each institution.

AALBORG UNIVERSITY

Aalborg University was founded in 1974 as a result of a social democratic intent to regionalize higher education, and an active student movement that hoped to reject older, scholastic approaches to higher education. Having been formed out of the merger of a number of educational institutions in the Aalborg area, including one of Denmark's engineering colleges (Aalborg Teknikum), the school turned away from a science-based approach to engineering education, embracing instead various alternative pedagogies. This included project-based learning, which came to stand at the core of its approach to teaching. However, given the geography of Denmark, and the relatively low mobility of its students (according to our interviewees), Aalborg University (AAU) emerged as a general university for the northern Jutland region. "Succumbing," as some would say to academic drift, the faculty became increasingly involved in sponsored research, even as the emphasis of its degree programs shifted from producing Diploma engineers, to producing those with Candidate's (masters) degrees, and eventually PhDs. Although project-based learning (PBL) remains an important part of an institution-wide commitment to alternative pedagogy, the "Aalborg Model" has also been made into a trademark or "brand" for the university.

The two principal challenges for Aalborg are those of choosing an appropriate strategy for growth, and maintaining appropriate balance between their established degree programs in Aalborg and the degree programs created at its new Copenhagen Campus. These challenges, along with the drift in institutional mission and pedagogy, are certainly related to the evolving context for Danish higher education. Reflecting the emphasis on neoliberal efficiencies, during our interviews educators and administrators alike referred to the difficulty they were experiencing in educating a larger number of students with approximately the same resources they had in the past. Being a regional institution located in the northernmost part of Denmark, AAU found it difficult to meet national mandates for expanded enrolments, both generally and within engineering. As paired with Denmark's general approach of enrolment based budgeting, this has produced fiscal challenges for the school. As described specifically by one of the senior educational administrators at AAU:

> *The most important decision that Danish politicians [have made] is that they allocate money based on education and [on] production of ECTS. So every time a student passes an examination, the institution gets the allocated [funds].*

It is important to note the neoliberal spread of more precisely defined accountability metrics. Instead of allocating resources to universities simply based on the number of students enrolled, the government now funds a university based on the number of students who graduate and pass their professional examinations, which could create incentives to focus on student retention and accelerated time to degree completion. As one of the major engineering colleges in Jutland, Aalborg University has also found it necessary to act in ways that continue to meet the industrial workforce requirements of the region.

The Principal Responses of Aalborg University

Implementing a school structure. Beginning with a conversation about institutional governance, Aalborg University executed a major reorganization in recent years during which it installed a new School structure across the university. Pursued ostensibly in response to the central government mandate to improve the efficiency of the university's operations, the School structure has made it possible, for example, to streamline the administration, standardize curricula across the university, and balance teaching loads, presumably through more rigorous application of the ECTS metric. It has also given Aalborg University the administrative mechanism it needed to make strategic choices about resource allocation. This in turn has fuelled more explicit planning about the university's future direction. Prior to the reorganization, most decisions were made at the level of individual departments or, for those matters related to curricula, study boards operating at the level of specific educations (degree programs). Instead, it has become possible for the Dean of a School to make explicit allocation decisions and strategic choices about what new degree programs to develop. This represents an administrative shift in authority from the academic staff to the Dean.

The Copenhagen Campus. While the organizational changes at Aalborg were a necessary step for undertaking bold strategic actions, the opening of Aalborg's new Copenhagen Campus represents Aalborg's most aggressive move to expand its enrolments and to reorient their institution around the new "innovation economy." It also amounts to a concerted effort to move beyond Aalborg's historic identity as a regional institution. The initiative began under the general framework of the Bologna Process, and the constraint that the Danish government placed on the engineering colleges (Teknikum). Thus, Aalborg University set up a facility in Ballerup across the street from IHK, where the expectation was that the engineers who received the Diploma (B.Eng.) degree from IHK would have the option to continue their studies and receive a candidate's (Master's) degree from Aalborg. However, given that the very reason for Aalborg to set up a new campus in Copenhagen was enrolment growth and the associated revenues that this would bring, there remained a basic tension in this arrangement. IHK wished to preserve the B.Eng. degree as an autonomous, terminal degree for a majority of its students. When the arrangement failed to produce the level of enrolments that were originally anticipated on the AAU side, and IHK felt in turn that AAU did not invest enough in research support for their teaching staff, the relationship between IHK and Aalborg turned sour. As a result, the IHK Board of Trustees as well as a new IHK rektor decided to terminate the planned merger with Aalborg, and to merge instead with DTU. (See the sections on IHK and DTU for more details.)

This break allowed Aalborg University to think more carefully about how it wished to position itself within the Copenhagen higher education market. Seeing little opportunity in offering more traditional engineering Master's degrees, and recognizing DTU's competitive position with regards to B.Eng. degree programs (DTU offered their own B.Eng. degrees), Aalborg University outlined a sharp profile for its Copenhagen Campus, aligning it much more explicitly to the new "innovation economy." Symbolically located in Nokia's former research and development headquarters, the Copenhagen Campus was dedicated exclusively to research-based educational programs at the master's level in selective and generally more specialized areas clearly distinguishable from the basic engineering disciplines. These degree programs, all of which are built around specific economic sectors, or "application domains," align with Aalborg University's pedagogic orientation and its focus on real-world problems. Aalborg University's administrators saw in DTU's strategic choice (see below) an opportunity to differentiate itself from its primary competitor. As stated by one of AAUs administrators:

> *As a vision it has always been, 'we are going to have only unique educations (degree programs) that [are] determined by the national market. We [took the approach of creating degree programs] complementary to the existing portfolio of education[s] that [are] out there in Copenhagen.*

This kind of entrepreneurial conduct was central to Aalborg University's response. The overall emphasis chosen for the Copenhagen Campus plays directly to the university's strategy for enrolment growth. This is consistent with the kind of market competition intended by the Bologna Process. In Denmark, it has cultivated competition not only across countries, but across higher education institutions within the country (stated by a senior administrator at AAU).

Changes at the northern (main) campus. In terms of total enrolments, the university's campuses in Aalborg still clearly overshadow the enrolments in Copenhagen. As such, an important part of the strategy for Aalborg remains the continuous renewal and revitalization of the degree programs offered in Aalborg.

While the scope of our visit was limited, we were able to observe three changes. The first had to do with the opening of a new downtown campus in the city of Aalborg, as represented by the new home for the School of Architecture, Design and Planning. Even with the strong emphasis on nature, sustainability, and natural lighting in Nordic architecture, architecture remains an urban profession and it was an obvious choice to open an urban campus. Second, Aalborg University had created something approximating the "tech park" concept in rented facilities located close to the main campus. Alborg's foray into the new high-tech arena of nanotechnology, for instance, was situated in such a location, providing an opportunity to combine existing faculty and strengths in physics, chemistry, and biology into a new research area and field of study. Finally, Aalborg's Master's program in Energy Planning was modelled upon the Bologna Process in the same manner as the specialized Master's programs offered at the Copenhagen Campus. It was designed as a degree program that could bring students in at the Candidate's level from the emerging European higher education market in a way that played to Denmark's technical and economic strengths.

By contrast, the fourth unit that we visited, the Global Business and Development degree program, demonstrated the curricular renewal efforts of one of Aalborg's traditional engineering departments, the Department of Construction and Production. A focus on construction and production, or industrial engineering, has long been a staple for Aalborg University and the distinct needs of the regional industries in northern Jutland. Still, the new degree program in Global Business and Development represents an effort to adapt to the same kind of forces that have been motivating the Bologna Process, in that it seeks to give students a more global and economically competitive orientation.

AARHUS UNIVERSITY (INCLUDING IHA)

At the time of our visit, the single greatest challenge for Aarhus University and the former Ingeniørhøjskolen i Århus (IHA) lay with the successful integration of the two institutions in completing the merger mandated by parliamentary decree. For those unfamiliar with its history, IHA opened its doors as a technician training school in 1828. During the early 20th century, the school received its designation as a Teknikum, one of eleven institutions in Denmark that eventually operated under that title. Like the IHK in Copenhagen, IHA "made engineers" for well over a century, seeking to provide for central Jutland's industrial workforce needs, even as it sought to ensure the social "betterment" of working class boys who obtained their education in a trade school instead of an academically-oriented (college preparatory) high school.[3] Meanwhile, Aarhus University operates as a general university with 36,000 full time students and 8,500 continuing education students, making it second in size only to Copenhagen University in Denmark.[4] It is also important to note that until it absorbed IHA, Aarhus University had no engineering program or faculty, apart from a group of agricultural engineers it acquired during an earlier move towards fiscal efficiency and consolidation when a national agricultural research institute was folded into the university.

We also take note of the special challenge that Denmark's aging engineering workforce created for industries located in the central Jutland region. Much of the anticipated engineering workforce shortages in Denmark and elsewhere can be attributed to a demographic bubble—the "baby boomers"—who at this point are expected to enter retirement. The concentration of traditional industries in Jutland has made this a special concern for the region's industrialists. The strong representation of industrialists on IHA's Board of Directors has no doubt allowed them to influence key decisions about IHA, including its decision to merge with Aarhus University. Aarhus and IHA's principal responses have been related to the merger and reorganization.

The merger. Nearly all of the former engineering colleges chose to align themselves with a general university rather than the new University College system. But while some colleges, most notably IHK in Copenhagen, delayed the process until the last possible moment, IHA was more quick to seek a partnership with Aarhus University (as was the Teknikum in Odense in relation to Odense University). The process began with the enterprising efforts of some of IHA's software engineering faculty, who were prohibited from offering a professional master's degree at IHA under the Danish implementation of Bologna. As a result, they forged a joint arrangement with Aarhus University so that they could begin offering the specialized instruction and Candidate's degree paired to the needs of an emerging, regional "high-tech" industry. As at other non-research based institutions in Europe (and the historic California case study we discussed in our other contribution to this volume), academic entrepreneurialism resulted in part from faculty and department-level initiatives, which then opened new policy options for the administration. It was on the basis of this program that broader discussions between IHA and Aarhus began on how to expand the relationship. A key to this negotiation was IHA's insistence, based on a survey of industry interests, that there remained a distinct regional demand for engineers among the industries located in central Jutland. Aarhus University, meanwhile, saw a merger with IHA as a means of entering the arena of engineering education, not only with a B.Eng. degree, but a new program in graduate engineering education and research based on the anticipated continuation of many B.Eng. students. The initial merger was completed in 2007.

While there is a real risk that the present arrangements will evolve, what is unique about the Aarhus-IHA merger is the expressed intent of maintaining a clear demarcation between the two different phases of an engineer's education. In order to create a clear differentiation in institutional roles and responsibilities following the merger, a decision was made to give the former IHA full responsibility for all baccalaureate education (B.Eng., or Diploma degree programs), while the new School of Engineering at Aarhus will assume responsibility for all graduate education at the Candidate's (M.Sc.) level and above. Aarhus University will not offer a B.Sc. degree in any engineering discipline; all engineering students are expected to go through the B.Eng. curriculum at IHA before proceeding, if they elect to do so, to the Candidate's degree.

Still, IHA and the Aarhus School of Engineering maintain separate faculties. By agreement, the IHA faculty continue to teach 40 ECTS per year (4 courses per semester), while the new faculty hired directly into the School of Engineering will have the typical Aarhus University faculty course load of 20 ECTS. The latter would come with substantial research expectations, including the supervision of theses produced by the Candidate's (Master's) degree students. While the "benefits" of this arrangement, as expressed in terms of the reduced cost of education for the B.Eng. degree are obvious, those affiliated with IHA suggest that this arrangement was as important for upholding the industrial orientation and affiliations of the IHA faculty. Because the IHA faculty are not considered research faculty, they are not required to have a PhD, and therefore can and are often hired from industry based on their work experiences, mainly within Jutland's regional industries. This remains important for supporting the more practical, hands on aspects of the IHA curriculum, which is expected to continue as a crucial part of their B.Eng. degree programs.

A broader reorganization. This being said, the 2007 merger simply permitted IHA and the fledgling Aarhus School of Engineering to operate as separate entities. It was the more recent 2011 university-wide reorganization that brought more far-reaching reforms in terms of the university's governance structure. This more recent reorganization was likely the result of the broader neoliberal impulse to rationalize Danish higher education; it did not come about as a result of the IHA merger. Nevertheless, the reorganization provided a comfortable rationale for placing IHA and Aarhus' School of Engineering under a single administrative entity and Dean. Also, as opposed to the significantly larger number of more specialized B.Eng. degree programs offered by IHA in the past, the plan at the time of our interviews was to offer exactly nine engineering degree programs, all with a strong focus on foundations. A strong, disciplinary focus can also be found in Aarhus' new Candidate's degree programs. This represents a significant wager, and commitment to the idea that the adaptability of Denmark's engineering workforce can best be accomplished through more rigorous training in the fundamentals. In their view, it is to shift IHA's education from an "experience" based curriculum to a "development" based one, where students are given the underlying knowledge and skills necessary to contribute directly to the development of new products and industrial processes. While it is acknowledged that interdisciplinary work is increasingly important to advanced engineering work, the Aarhus School of Engineering's vision of interdisciplinarity is based on assembling a team of engineers and other specialists from various basic disciplines, and hiring each at the right level of competency required for a particular task (whether a B.Eng., M.Sc., or PhD). This approach also takes into account the fact that some significant percentage of IHA's engineering graduates still go on to find employment as the first engineer hired by a small or medium industrial enterprise (this was said to be on the order of 40%). The suggestion is that training students in the fundamentals would give graduates the adaptability she or he needed to adjust to the diverse range of tasks to be found in such a workplace.

INGENIØRHØJSKOLEN IN COPENHAGEN (IHK)

At the time of our visit, IHK remained a separate entity from DTU. Given the substantial differences in IHK and DTU's concerns, and the interesting contrast between IHA and IHK, we report separately on the developments at IHK.

Similar to IHA, the Copenhagen College of Engineering opened its doors as a technician training school, evolving to produce its first professional engineer in 1881. The College was established specifically as an alternative to the polytechnic orientation of DTU, whose graduates typically secured elite public sector employment, leaving unfulfilled the engineering workforce requirements of Copenhagen's engineering industries during the height of the industrial revolution.[5]

Like IHA, IHK faced as its principal challenge its successful navigation through the mandate to complete a merger with an established university. The demographic and fiscal challenges that IHK faced were similar to those at IHA. The one obvious difference is that being the sole remaining engineering college in the metropolitan environs of Copenhagen, IHK stood as the beneficiary of the limited mobility of those remaining students with the relevant educational profile. On the other hand, the diversified economic activities of a major metropolitan area also created greater competition among degree program options, which contributed to historic declines in IHK's enrolment. The fact that a full 80% of the students at IHK now enter via the high school entrance exam may also suggest that social demographic trends away from the working-class identification of engineering may be more pronounced in Copenhagen than in Jutland. Likewise, although the board of trustees for IHK, as for IHA, is set up to represent regional industrial interests, the specific industries that look to IHK for its engineering workforce are different from those found in Jutland. Such factors have shaped IHK's options and responses.

The merger. We have introduced part of IHK's story in our discussions about Aalborg University. In order to describe the event from IHK's point of view, it is important to note that, from our understanding, it was Fleming Krogh, a former rektor at IHK, who helped create the University College system. Those who supported the scheme, or went along with it, no doubt viewed it as a necessary compromise given that they were blocked from gaining the authority to grant professional master's degrees.

When it became clear that better opportunities lay with a merger with the university system, Krogh, as IHK's rektor, made arrangements for IHK to merge with Aalborg University. The original arrangements with Aalborg were constructed quite explicitly along the lines of the early plans under Bologna, so that IHK B.Eng. degree recipients could obtain, through several additional years of part-time study (or full time study after some interval of employment), a Candidate's degree as financed by regional industries. In addition to satisfying the legislative mandate and policies favouring the expansion of studies at the Candidate's level, the hope was that by making it easier to complete a Candidate's degree after graduation, this might also make IHK's B.Eng. degree more attractive to prospective students. This was important given waning enrolments amidst the many other options for study in Denmark's major metropolitan area. However, the results were not as expected according to a senior administrator at IHK:

> *The idea was that Aalborg University should provide continuing education at the Candidate's level, so that our graduates could continue and get a master's, [a] Candidate's degree. This was set up and it was not a great success, because*

> *I think the students [choose] us not because they would like to get a Candidate's degree, [but because] they don't want to get a Candidate's degree.*

In other words, most IHK students still choose to get a job right out of college and be done with their education.

Krogh's successor was Conni Simonsen. In her early meetings with the Board of Directors, she decided that it was pointless to fight the legislative mandate, and determined that the key issue for them was choosing a university that would most likely enable IHK to retain its distinctive B.Eng. degree program. While some of the board members regarded Aalborg to be the natural partner—IHK's pedagogic strategies as well as its orientation towards practical training was more closely aligned to Aalborg's style of education—it was evident to many that Aalborg had, from their point of view, suffered from academic drift. Indeed, there was a specific policy difference. Whereas Simonsen and her Board of Directors saw 30–40% as the ideal percentage of Diploma engineers who would continue on to seek the Candidate's degree, Aalborg's administrators, during our interviews, openly spoke of their goal of converting more than 50% of B.Eng. students to the Candidate's degree. Simonsen expressed earnest admiration for Aalborg's ability to respond to new global opportunities, but indicated that she found the university's strategic orientation to be inconsistent with IHK's desire to preserve its distinctive B.Eng. degree program.

Whether this represents an entrepreneurial response or a bureaucratic one that followed from established governance structures remains a bit unclear. Simonsen had been the Director of all of Ericsson's Danish operations, was involved in starting up Ericsson's operations in Lithuania, and so it appears that her appointment was itself one manifestation of the neoliberal turn in Danish higher education. An astute executive with a strong corporate background, Simonsen ascertained quite quickly that DTU would be experiencing similar enrolment problems in its B.Eng. degree programs. As described in greater detail in the following section on DTU, open enrolment policies and Denmark's enrolment-based financing of higher education had already prompted DTU to embrace the B.Eng. degree as a way of attracting engineering students who were not drawn to DTU's academically oriented Candidate's degree. Whether as an entrepreneurial move, or an institutionally conservative one, Simonsen's approached the DTU administration, reasoning that by taking the initiative, it might be possible to strike a deal that would ensure the continuation of IHK's B.Eng. programs under terms more favourable to its educational philosophy.

Still, with DTU, there is actually the same difference in their target conversion rate for the Candidate's degree (also 50%, which, not coincidentally, is a reflection of national policy). Nevertheless, the physical proximity of DTU, and its emphasis on the engineering sciences, meant that IHK and DTU students could share instructors and classes for the more basic engineering courses, enabling IHK's more industrially oriented faculty to continue focusing on applied areas of study. Though perhaps a post hoc construction, Simonson states that one of Aalborg's disadvantages was that they had no intention of assembling a basic engineering faculty in Copenhagen—a point that has since been affirmed by the current Dean of the School of Engineering and Science at Aalborg.

In any event, IHK and DTU were at the point of working out the details of the merger when we visited them in October of 2012. The merger was completed in early 2013. In the final arrangements, IHK was set up as a semi-autonomous institute (an academic department) with its own director, and currently operates under the label DTU Diplom. Its director serves as the Vice Dean for Undergraduate Education responsible for all Diploma (B.Eng.) instruction at DTU, in effect giving administrative control over all B.Eng. programs to the former IHK. At the time of the interview, it was already anticipated that a majority of the B.Eng. program would be conducted primarily out of the former IHK campus, although a number of DTU's B.Eng. programs that rely heavily on DTU faculty or facilities, such as the DTU B.Eng. program in Building Design, were expected to remain on the DTU campus. This being said, a difficult challenge remained at the time of our interview in terms of how the individual B.Eng. degree programs would be refashioned in the months following the merger, especially where DTU and IHK nominally offered the "same" degree program (this, we presume, would have primarily been in the basic engineering disciplines). While our interviews did not ascertain this level of detail, we anticipate that differences would have cropped up, both in content and pedagogy, because of, on the one hand, the practical orientation of IHK, and the attempt at DTU to offer a more integrated program that would enable more students to shift over into an associated Candidate's degree program.

Other responses. The merger occupied a significant part of the IHK administration and faculty's attention, given that it bore upon the very survival of their institution. However, IHK pursued other strategies, partly in an attempt to improve their profile going into the merger. This included the decision to launch three new degree programs in Health Technology, Sustainable Energy, and (Industrial) Process and Innovation. Many of these programs represented efforts to repackage and recombine existing programs, as was the case with the Global Business Development Program at Aalborg, and were consistent with the Bologna Process' emphasis on creating a more specialized, globally competent workforce.

Like IHA, and as consistent with the broader trend within neoliberalism to emphasize public-private partnerships, the IHK administration took steps to enhance their relationship with regional industries. While the uniform implementation of a semester-long industrial internship perhaps came with the Bologna Process, there is now an effort to refashion faculty involvement with internship projects into a consultancy-type arrangement. The hope is that some of these partnerships might translate into corporate-sponsored product development and testing contracts for the IHK faculty. To promote such developments, the IHK administration formally re-allocated faculty time from 100% teaching to 80% teaching and 20% "development." This was cast by some as an attempt to retain IHK faculty amidst fears about the proposed merger, although it remained unclear whether, in the short run, this was accompanied by any actual reduction in teaching load.

TECHNICAL UNIVERSITY OF DENMARK (DTU)

One significant limitation to our site visit to DTU resulted from the fact that we did not gain access to the senior members of the DTU administration. Our interviews were limited to the departmental level. Nevertheless, given DTU's stature within the Danish engineering education community, and the clear contrast in its response, we provide what we can about DTU's present orientation, some of it based on published sources.

It should be safe to say that the single greatest challenge for DTU rests with charting a proper course for Denmark's leading technological university amidst the general remaking of European higher education. DTU is one of the world's leading research universities and competes head-to-head with the best technological universities and polytechnic institutions in Germany, France, and elsewhere. Established in 1829 under the model of the French École Polytechnique, DTU, from the outset, emphasized a more formal approach to engineering and engineering education that remains its signature approach today. The institution assumed its modern form by around 1933, merging with the Danish Engineering Academy in 1994 to officially become the Danmarks Tekniske Universitet. In 2007, five different Danish national research centres that had been operating independently were also folded into DTU. DTU remains influential in national policy circles, including those pertaining to research, innovation, and of course higher education.[6]

However, because of the strong social democratic traditions of Denmark, DTU has been cast in a mould somewhat different from the other TUs in Europe. Despite the elite status of the DTU faculty, the largely open admissions policies of Denmark, along with fiscal policies that compel Danish universities to compete for enrolments, have made DTU a far less selective institution than their counterparts in central Europe and the US. DTU's decision to embrace B.Eng. educations even prior to its merger with IHK is therefore just one part of the institution's overall enrolment strategy. We should add that the limited mobility of students away from the Copenhagen area, conjoined with the fact that DTU is now the only remaining school in the region with a strong capacity for engineering education, has required DTU to operate as a regional institution for engineering education, even as it operates as a research university with an international reputation. DTU remains, simultaneously, the preferred school for many students across Denmark who seek the more advanced Candidate's degree in engineering.

The DTU faculty has also had to contend with subtle changes in its student population. As has been the case with other countries, the increased "career" orientation of students, growing interest in business, the health sciences, and finance, and the declining stature of the physical sciences vis-à-vis these other disciplines have resulted in the stagnation, if not decline, in the number of students interested in more formal and analytic approaches to engineering.

The different demands and expectations that are placed on DTU make it all the more difficult for its faculty and administration to chart a proper course for their institution. The present transformation of the global technological research and educational infrastructure presents a complex array of opportunities and challenges for DTU. As historians, we might compare DTU's present situation to that of MIT in Boston at the end of the Cold War era, when the MIT faculty and administration deliberated extensively about the proper course for their institution amidst anticipated declines in federal and military research expenditures. The multiple policy demands that are being placed on DTU, including the basic tension between educational access and academic excellence, makes it less certain that DTU can find an equally successful strategy for its institutional reconversion. At DTU, we found the major responses related to disciplinary policies and enrolment.

Disciplinary retrenchment. From what we were able to observe, it appeared to us that one of DTU's major responses was that of disciplinary retrenchment. Because of the mandated improvements in administrative efficiency, DTU streamlined its organization in the recent past, merging multiple academic departments and research institutes into a leaner administrative structure with far fewer departments. This move, in itself, shifted DTU's emphasis towards more traditional science and engineering disciplines, even though each department maintains multiple sections and study boards within which more specialized research and educations, including specialized Candidate's degree programs, can take place. While fields such as production management and economics continue to be offered, being considered still central to engineering professional identities, broader knowledge in the social sciences and other disciplines have been deemphasized as being more marginal to DTU's identity.

Enrolment management. As with other premier research universities across Europe, DTU initially regarded the Bologna Process to be something of an annoyance. While the necessary articulation has been made between related B.Sc and M.Sc degree programs to enable international student transfers into DTU, most DTU B.Sc. students are expected to continue their studies at DTU and obtain the higher, M.Sc degree. Officially, DTU claims that it does not wish to expand enrolments; it is satisfied teaching those students who do have the orientation towards science and the applied sciences that DTU considers its brand and benchmark. Nevertheless, we believe that various changes, including DTU's decision to embrace B.Eng degree programs even prior to its merger with IHK, reflect institutional decisions related to underlying concerns about enrolment.

DTU has also introduced new degree programs that are designed to be more popular with students and has the potential to attract new demographic cohorts to DTU. For example, its Design and Innovation program as well as its Architectural Engineering degree program (offered both as a B.Eng. and B.Sc. degree program) has a higher female/male gender ratio as compared to established engineering degree programs.

Research and institutional organization. Meanwhile, research, including PhD production, remains the principal policy priority for DTU. While we heard of no explicit incentive structures, such as the internal seed grant programs often used in the United States (and explicitly visible in the Texas case study from Chapter 2 in this volume), the faculty at DTU are actively encouraged to seek external funding for their research. The sectional organization within academic departments remains an important vehicle for rewarding the most successful research groups, which are given semi-autonomous status within DTU's administrative organization. This in fact seems to create a bifurcation among the academic units at DTU, with certain sections, whose faculty have less external support, having primary responsibilities for undergraduate instruction, while other sections are able to focus more heavily on their PhD students and the further cultivation of externally funded research. M.Sc. education appears to be distributed across both, although the primary responsibility for administering the M.Sc. degree programs may rest with the former. As at other Danish universities, interdisciplinarity is said to be an institutional strategy, although here again, we found no specific incentive system designed to promote or recognize interdisciplinary teaching or research.

Governance. Our final observation about DTU has to do with the locally more delicate issue of governance. The language employed in the DTU website demonstrates, in no uncertain terms, the effects of neoliberal influence on the administrative structure of DTU. References to phrases such as "unbroken chain of command," and "line and staff organization" indicate a shift in academic culture away from the tradition of faculty autonomy and shared governance that characterized Danish academic institutions in the past. We believe these changes were necessitated in part by the considerable (some would say excessive) degree of autonomy granted to DTU faculty in the past.[7] The lean administrative structures that prevailed within Danish universities were incapable of accomplishing the changes associated with the Bologna Process, and this may have been especially true at DTU. Both at DTU and elsewhere, the expansion in the authority of the central academic administration represents a structural adjustment that came with the basic decision to embrace the market oriented conduct suggested by the Bologna Declaration. Given the stature and historic autonomy of the academic departments at DTU, the changes there have been pronounced.

FACULTY PERSPECTIVES ON CHANGE

Before we close, we wish to discuss faculty perspectives on the present changes in Danish engineering education. Direct mention of the Bologna Process was rare. Nevertheless, it was clear that study board directors and even department heads, who continued to identify strongly as faculty members, held conflicting views about the changes that they inhabited.

It was clear that many of the faculty members who were given administrative duties were feeling the effects of new neoliberal "efficiencies." Many spoke of the personal burdens of unfunded mandates and resulting uncompensated labour associated with carrying out a broad transformation of Denmark's system of engineering education. For example, two of our subjects stated the following:

> *The money which are given to the university to run the education, they are always lagging behind [enrolments]. It could be invisible things like you need to update your course materials, and this is more urgent when you have [new kinds of students]. [We get a fixed] percentage of the money which are allocated, but if the clock needs to run faster which will require more money, [you still] don't [get it].* (Head of section, university)

and

> *The most frustrating [thing for] teachers [is] that we have to cut down in [the] time that you spend in direct confrontation (contact) with the students. … because with the [allocation formulas] you get a certain amount of money [for] hours paid for your teaching activities, and [the time allowed] has been dramatically reduced with the change in the school system. That was [frustrating] for teachers because the teachers typically want to give the students a good education… the more confrontation (contact) time you have, the better, typically.* (Head of department, university)

As indicated by the latter quote, the faculty did not always agree with the policy decisions of the upper administration, implicitly (and sometimes explicitly) arguing that different allocations were necessary to ensure good learning outcomes, or that they required support for the different teaching and learning strategies that some students needed to attain academic success.

In general, the resource problems that were mentioned had little to do with physical facilities. Reorganization and enrolment growth brought new resources and facilities to many of the academic units that we visited, so that the principal problem lay more specifically with faculty lines and faculty time, or else rules and allocation decision that placed restrictions on how faculty allocated their time (as also indicated in the second quote above). There was also concern about the erosion of faculty time for research. Asked whether the nominal allocation of 50%/50% time spent on research and teaching at his/her institution was true in practice as well as policy, one faculty member responded:

> *In terms of [actual] practice, no, because of [administrative responsibilities]. You have to do a lot of administration and you have to take that from somewhere. And it's easier to take [time away] from research than from teaching.* (Head of department, university)

Another faculty member, in speaking about the hours he spends supervising a candidate's thesis stated,

> *This 30 hours, I can tell you realistically it may be three times as much… And where do these hours come from? They come from my research or from my spare time. I work 70 hours per week. … So you get 30 hours for doing 90 hours' work.* (Head of section, university)

This being said, the administrative faculty members we spoke with were quite willingly engaging in curricular reform efforts. Several individuals we spoke with embraced this work with enthusiasm. While we believe we had a biased sample, in that the people we spoke with all had responsible positions for implementing institutional change, they nevertheless expressed the view that it was necessary to pursue such work in responding to changing student interests, demographics, new technological opportunities, or else industry needs. Most interviewees clearly regarded it as part of their professional responsibilities as educators.

We anticipated that there would be greater apprehension, if not anger, among the engineering college faculty, given the mandated mergers. And while we did hear rumours about faculty concerns and discontent, and the sample bias here was again most likely determining, there appeared to be faculty at both of the engineering colleges we visited who were willing to embrace the challenge of remaking their institutions under a new vision.

> *[At some level within the administration, there was a decision] to keep [the] different cultures. [We] will fight very hard to keep the engineering culture at [this] university, because that's very important. We have a long history of doing engineering education at this location, and there is a strong tradition of doing science education at the university. In this [merger], we can really see the very clear benefit of the [merger], but we also try to maintain at least the best of the [two] cultures.* (mid-level administrator, engineering college)

While more centralized academic administration is often integral to neoliberalism as experienced in higher education—and it appears to be a necessary corollary to the Bologna Process—there were nevertheless considerable differences with regards to how each administration related to their faculty. As contrasted against the clear top-down style of administration practiced at DTU, Simonsen's approach at Aarhus was based on a consultative process designed to win over the IHA faculty, and is perhaps more compatible with modern approaches to corporate management.

Although faculty responses to the centralization of academic administration have so far remained muted, to the extent to which the neoliberal turn in public administration is at odds with a strong shared governance tradition within Danish universities, the risks associated with the alienation of faculty remains and should be given careful consideration by all universities.

CONCLUSIONS

With the empirical details before us, we can assess to what extent the neoliberal dimensions of the Bologna Process have extended into the strategies for change and the daily conduct of engineering education institutions in Denmark. More abstractly, we are interested in the extent to which this constitutes a significant redeployment between the public and private sphere in higher education. It is clear from our account that entrepreneurialism has permeated deeply into Danish educational institutions, as represented not only by the egregious case of Aalborg University, but in a variety of actions such as Aarhus University's decision to create a new School of Engineering, and to open a new harbor campus built on a specific vision of interdisciplinarity. The corporate managerial approach to IHK's merger with DTU, and IHK's earlier efforts to remake its degree programs in the name of restoring enrolments and improving its bargaining position also illustrates strategic initiatives at an institutional level. This kind of conduct stands at the very heart of the Bologna Process, whose intent has been to strengthen European institutions of higher education by fostering competition across institutions, promoting greater specialization, and encouraging institutional change and innovation. We found this to be occurring at all of the sites we visited, even DTU.

This being said, DTU represents one end of the spectrum. Like other top tier universities in Europe, DTU has little reason to embrace the Bologna Process in its entirety, and has done what it can to convince its students that they should stay at DTU through the Candidate's degree. Changing student interests and demographics, Denmark' commitment to access, and enrolment based budgeting have forced DTU to respond by embracing more specialized and applied degree programs, including medium-cycle B.Eng. degree programs. But it is clear where DTU's priorities lie. Indeed, in looking more closely at all of the institutions, it is clear that there is a range of responses with regards to Bologna. Aalborg has been the most aggressive, IHA and IHK embraced entrepreneurial solutions out of necessity, while Aarhus responded willingly to new opportunities created by the new emphasis on science and technology and an innovation economy. In this respect, DTU, aside from using corporatist governance techniques to gain more firm control over their own faculty, has been less eager to embrace change and has tended to create new degree programs only as a defensive measure. So even though a new level of market competition has appeared among Danish engineering schools, this has occurred within a specific policy context overseen by more traditional approaches to governance.

Indeed, the social democratic traditions and visions within Denmark stand in odd juxtaposition with the neoliberal strategies that have animated the Bologna Process. Far from producing an irreconcilable tension, this has provided fertile rhetorical ground for the highly varied solutions that we observed in Denmark. All of the solutions seem to be animated by economic concerns, certainly when compared to earlier articulations about Denmark's social vision. But in fairness, economic interests have tended to dominate the European political scene since the origins of European integration, and in Denmark certainly since the 2008 financial crisis. We have also seen the complex outcomes that can emerge out of a basic policy decision, as was the case with the mandated merger of the engineering colleges.

What is perhaps most striking about our findings is the extent to which the schools have chosen complementary strategies, not only with regards to the kinds of degree programs offered, or their strategic posture with regards to research, but with respect to intellectual commitments vis-à-vis things such as disciplinary retrenchment and interdisciplinary programs. From the standpoint of innovation, diverse approaches are more likely to produce diverse outcomes. There is no guarantee that any of these approaches are well-suited to the present situation in Denmark or that they will be productive. The interdisciplinary model espoused by Aarhus University may not be sufficient to address the cross disciplinary challenges that exist in the newest high-tech sectors. DTU may have narrowed their horizons too much to remain a player in certain markets important to Denmark's economic future. AAU may falter for other reason entirely, such as becoming overextended in ways that leave them vulnerable to changes in educational policy or the higher education market. Certain approaches may only be suited to specific fields and industries. But although not every strategy may pan out, those that do are likely to be emulated by the other institutions in ways that realize a more agile system of higher education. It is perhaps in this sense that there has indeed been a significant redeployment and realignment of public and private interests which, if still incomplete, is occurring in Denmark.

We have one final remark about neoliberalism: Our US historical case studies from our other chapter reveal that this kind of entrepreneurial conduct in higher education is not unique to Europe, nor to the period of neoliberal economic reform. If neoliberalism has introduced a new logic into higher education, it has been through specific bureaucratic machinery, and especially through new measures of accountability. Though our evidence here remains limited, faculty responses indicate not only that there are many who feel saddled by the new accountability metrics, but that the metrics map neither onto the state's policy objectives nor the needs of their students. Indeed, as we have seen in other debates over public education, the increased emphasis on accountability has only been as effective as the measures used to document accountability, and many of these measures—such as standardized testing in US K-12 education—have proven quite contentious. The decisions about what to measure and what metrics to employ remain political. It will be important not to lose sight of this fact as we continue to study the overall impact of the Bologna Process.

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NOTES

[1] Throughout this account, information is based on interview data, as occasionally confirmed through additional sources including Hans Schjær-Jacobsen (2010). Sources and interview subjects often will not be identified except with respect to quotes, which will always be attributed in general terms by position and type of institution. The passage here and immediately below is derived, for instance, from: Interview, senior administrator, engineering college. No reference will be made to whether an individual is currently in the attributed position, to enhance anonymity.

[2] We note here the similarity of these events with efforts described in our other contribution to this volume. However, in the 1950s, the Cal State Colleges fought *for* the formal recognition of their right to offer occupational versus professional degrees, this as a strategy for allowing them to teach engineering in the first place.

[3] IHA's history can be found at the Aarhus University website at this location: http://scitech.au.dk/en/about-science-and-technology/history/engineering-college-of-aarhus-iha/ (Accessed 6/23/2014).

[4] For Aarhus University's history, see: http://www.au.dk/en/about/profile/history/history/ (Accessed 6/23/2014).

[5] Historical information on IHK was found on the IHK website, http://int.ihk.dk, which is no longer available following the merger. Limited background information about IHK may still be found on Wikipedia at http://en.wikipedia.org/wiki/DTU_Diplom (Accessed 6/23/2014).

[6] Wikipedia entry, DTU. http://en.wikipedia.org/wiki/Technical_University_of_Denmark (Accessed 6/28/2014).

[7] DTU, "Organization" (website). http://www.dtu.dk/English/About_DTU/Organization.aspx (Accessed 2/7/2013).

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PART 2

ENGINEERING EDUCATIONAL PRACTICES

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4. ENVIRONMENT AND SUSTAINABILITY CHALLENGES TO ENGINEERING EDUCATION IN DENMARK

INTRODUCTION

In this chapter, we discuss the practices of planning for sustainability in engineering education by examining the ways environment and energy and later sustainability issues have been incorporated in the educational programs at the Technical University of Denmark (DTU) and at Aalborg University (AAU) since the 1970s. These are the two most important research universities providing engineering education in Denmark, measured by numbers of programs and students. At these institutions, engineering educators and students undertook a variety of different initiatives covering a range of possible responses: from in practice no response, to the inclusion of new topics, to reforming the structure of engineering programs, to the transformation of the thematic and disciplinary content of the educational programs. These various responses observed at DTU and AAU are also found at other engineering institutions around the world (Sterling, 2001).

How to respond to the sustainability challenges is debated at engineering universities in Denmark as well as in other countries – for example, such questions as: Should sustainability penetrate all educational programs as a fundamental aspect or is it a new subject matter that must be addressed specifically through new curricula elements or in dedicated programs (Interview HB, 2013; Segalas et al., 2009)? What should engineering students learn in order to be able to cope with sustainability? A comparison of bachelor engineering education competences at three European universities demonstrates how fundamental this challenge is assessed to be in relation to engineering knowledge and practice (Holmberg et al., 2008). It also opens for new perspectives that transcend the top-down approaches that in many fields dominates engineering training (Mulder et al., 2010).

Promoters who view sustainability as a fundamental aspect believe that it provides a new and crosscutting set of values that should explicitly frame all types of engineering activities in line with the existing quality, efficiency, ethics and service provision. It is not clear, though, how these values are linked to specific methods or topics or maybe implicit in the values taught. However, although agreement exists

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about the need for a general re-orientation of engineering engagements towards sustainability, there are profound controversies about how to do this in engineering teaching and learning.

The discussion of how to respond to the sustainability challenge is in several ways a repetition of similar controversies that started in the late 1960s over how to respond to the environment and energy crisis, which related to societal concerns, formation of new government bodies, and the first global UN conference held in 1972 in Stockholm.

The three sets of challenges – environment, energy and sustainability – are tightly connected in several ways. Mulder (2006) argues that there have been two waves of incorporating environmental issues in Europe's traditional engineering schools: the first has focused since the 1970s on environmental pollution, water issues and energy; and the second wave started in the 1990s when the Brundtland report was taken up at many institutions. This resulted at first in sustainability issues being conflated mainly with traditional environmental issues, but increasingly it has included issues crosscutting impact on growth, inequality and resource use. In both cases, traditional engineering universities have provided more room for specific scientific and technique-oriented research programs such as water and waste management, Life Cycle Analysis (LCA), chemical processes, emission control and so on. In contrast, broader environmental and sustainability issues like environmental justice and social justice have regularly been left out of the engineering curricula, as they do not cohere with dominant disciplines within these educational programs (Mulder, 2006).

The broadening focus on the strategies for the development of new programs constitutes a contribution to the literature on engineering education and sustainable development that has otherwise focused in discreet courses (Kamp, 2006) and on incorporating sustainability in single existing programs (Chau, 2007; Costa & Scoble, 2006). Whole institutional initiatives that incorporate sustainability in all university programs (Kamp, 2006; Mulder, 2006), requirements for incorporating sustainable development in the education of engineers (Barry, 2007; Sterling & Thomas, 2006), and focus on learning through problem- (and project-)based learning (PBL) (Kamp, 2006; Mulder, 2006) have been part of this development.

In the next section, we present the methodological approach behind the research. Then, we account for how environmental and energy issues have been taken up at DTU in the practices of education and in the organisation of research, followed by the parallel, but also rather different practices carried out at AAU. To be able to trace the practices, we focus on codes of meaning and translations. This leads to a discussion of how especially AAU has been incorporating new educational programs and practices as a response to sustainability issues. Finally, we discuss the different responses and disciplinary practices within engineering, when confronted with the new societal challenge of sustainability.

METHODOLOGICAL APPROACH

To investigate response practices, we have conducted a historic study of how educators, managers and students at DTU and AAU, during a period from the 1970s to the 1990s, exhibit contrasting practices concerning the changes in educational programs and the structuring of research. The chosen period represents the first wave of responses to the environmental and energy challenges that during the 1970s were regarded as a societal crisis concerning pollution and depletion of resources. This serves as background for the analysis of contemporary controversies and response practices that reflect the second wave, which deals with the sustainability challenge initiated since the 1990s.

Our methodological approach builds on two developments in the anthropology of science, technology and engineering, which put forward the following two concepts: codes of meaning and translation. Engineering educators react to internal institutional signals and outside contextual developments by developing educational projects (courses, modules and entire programs). These are 'codes of meaning' (as suggested by Downey & Lucena, 2004) in the sense that they are complex objects that propose particular ways of coupling knowledge, institutional arrangements, students' interests, research results, future expected work demands and institutional and disciplinary traditions. Therefore, codes of meaning are not stable objects but the result of several translations. According to this view, translations are understood as proposed by Callon (1986, 2004) as the process by which actors are interested, enrolled and mobilized to support a given initiative or code of meaning. Thus, a given innovation in education, for example the idea of educating engineers in the fundamentals of ecology, is not merely a proposal to train future engineers in a particular body of knowledge. It is also a proposal to re-think what kind of knowledge engineers should be able to command; how they should be trained; what their role in society is; and how the institutions that train them should evolve. Depending on the ambition of the proponents of a given initiative, engineering educators have to interest, enrol and mobilize others, such as the head of the department in which they work, the committee responsible for a specific educational program, the accreditation bodies, influential external partners, or sometimes all of them.

These processes are not only about creating new alliances between existing actors, but also about interrupting relations and even challenging established or competing codes of meaning. For example, those who proposed training engineers in the fundamentals of ecology challenged the idea that engineers' core disciplinary foundation should only be mathematics and physics.

Thus, our methodological approach builds on the theoretical developments of ethnographical and historical accounts of engineering cultures. Following Downey and Lucena (2004), we consider engineering educators not as passive agents that react to external social influences or to institutional top-down strategies. Instead, engineering educators are active academic entrepreneurs who, through their practices in teaching and research, develop new engineering knowledge and curricular contents. These dynamics are what was characterized as ‘response strategies’ in the research approach of the PROCEED project, which provided the funding and intellectual environment for the studies presented with its focus on how institutions, scholars, staff and students responded to the external pressures and challenges. The focus on practices led us to look into these actual responses and what they entail by framing challenges and engineering training instead of searching for a specific and essential identification of the challenges.

DTU and AAU have quite contrasting institutional and educational profiles. DTU, founded in 1829, is a traditional science-oriented engineering institution with strong disciplinary programs and ties to research-oriented industries in Denmark as well as internationally. AAU is a younger university, which also covers social science and humanities with a cutting-edge pedagogical approach where all educational programs incorporate problem- and project-based learning (PBL) as a principle, and where interdisciplinary education is the norm rather than the exception. Since its founding in 1974, AAU’s engineering research groups and teaching programs have developed strong ties with traditional product-oriented industries as well as fast-changing engineering industries, including small and medium-sized businesses (Jamison, 2012).

The historic analysis of the responses in the fields of environment and energy builds on semi-structured interviews with 25 engineering educators at DTU and AAU (carried out during the period 2011–2014) combined with document analysis. We applied the general principles of situational analysis to guide our research choices. We selected the interviewees using a snowball technique to identify relevant sources based on the first interviewees, and we completed the sample according to the saturation principle (Clarke & Leigh Star, 2008; Clarke, 2005).

The contemporary responses to the sustainability challenge are based on curricula documents, participant observations by the authors involved in the processes at both DTU and AAU, and four complementary follow-up interviews with actors involved in the sustainability discussion.

THE EMERGENCE OF ENVIRONMENT AND ENERGI AT DTU

One of the first ‘wake up calls’ in the Danish engineering field to focus on environmental issues was a series of discussions in the Danish Engineers Association (Dansk Ingeniørforening) in 1964. In four transactions presenting those discussions, environment was divided into issues related to air, soil, water and chemicals (one transaction for each of these items). In 1972, at the United Nations Conference on the Environment in Stockholm, these challenges were given international articulation and were further strengthened, making engineering professionals feel the need to take action in order to “clean up the mess” produced by industrial societies. At the same time, researchers who were members of the Club of Rome at MIT concluded that the world was reaching a level of resource use that would deplete the planet in the course of a few years (Meadows et al., 2004). These attempts at framing environmental issues inscribed themselves within a code of meaning that conceived the world as a set of physical elements to be handled through careful measurement, modelling and technical intervention.

To attend to these concerns, students, faculty members and administrators at DTU in the late 1960s and 1970s began the first activities to meet the increasing environmental challenges facing the country. The Laboratory of Technological Hygiene, which was established in the late nineteenth century and framed the environment in terms of controlling wastewater, began to take up new courses to broaden their scope from sanitation to environmental pollution. Prior to the reframing of focus, the Laboratory focus had merely been on water: *It was all about water in and out of urban areas – how do we get clean water, how do we treat it, how do we get rid of the water, including rain water, and how do we treat it* (Interview PK, 2012). The reframing of the Laboratory's focus meant that the focus also began to include aspects of *…chemicals, metals, effects in the environment, human health not only related to bacteria and waste* (Interview PK, 2012). Nevertheless, the focus was on controlling pollution rather than means of prevention.

The Department of Fluid Mechanics and Water Constructions, an institute concerned with how water flows in general, began broadening its focus with how the flows of ground water could supply clean water and also prevent contamination of clean water wells. Another set of activities was conducted at the Chemical Department on the burning efficiency for the production of energy; at the same time, they developed a whole set of courses in Chemical Processes and Environmental Analysis for educating engineers interested in environmental issues. The professor in charge of this department had the perspective *that chemical engineers should learn about the effects on the environment with a focus on chemicals, chemical production and its effects. They also focused on non-urban issues; ecology* (Interview PK, 2012). PK, who was a student during this time, mentioned that during this period a disagreement existed between the Laboratory of Technological Hygiene and the Chemical Department, *because they had very different opinions about what was important when working with the environment* (Interview PK, 2012).

These activities all strengthened the code of meaning within existing domains of engineering knowledge and professional practices related to waste water handling, supply of fresh water, efficient use of fossil fuels, and chemical processes with emphasis on pollutants.

However, another new topic was introduced by a professor of physics after a visit to the system dynamics group at Meadows in the US. He started research and teaching in renewable energy. In contrast to earlier, teaching of these topics introduced a new perspective on energy compared to what had hitherto been included in mechanical, electrical and chemical engineering covering only specific energy technologies and fuels. The outlet for these new perspectives were new disciplinary elements presented in new as well as existing courses. Energy savings and systems teaching were the fields that introduced the most radical new elements (Interview JH, 2013). These new perspectives gave rise to conflicts at DTU, because at this time, becoming engaged in societal challenges was interpreted as being political. *At DTU, the rules of the game are that you don't interfere with politics. You are a scientist and you keep to science. I was accused of doing politics. My colleagues didn't like that. It is different now because people realized that DTU has something to do with society* (Interview NM, 2013).

At that time, DTU was organized in departments that cohered around research agendas defined by professors and depended highly on the leading professor. During this period, four classic engineering programs existed: Civil, Mechanical, Chemical, and Electrical (Jørgensen, 2007). Administrated centrally by study boards, faculty members from the departments were requested to teach their subjects according to their particular competences. Parallel to the dramatic increase of new topics, the entire educational curriculum was reformed in 1972 with the introduction of a modular structure, which gave students the freedom to choose elective courses and created room for an expansion of the number of topics and courses offered by the different departments. This educational reform also made the creation of new experimental courses much easier, and gave the students room to organize their own project activities as long as they could engage teachers as supervisors.

Engaged students wanted more than just the possibility of choosing between existing courses or defining their own project assignments. An outcome of students' active engagement at DTU, in collaboration with the broader student movement, was the Danish legislation of 1973 giving students mandates in the governing bodies of universities. Around 1976, a group of students and teachers engaged in the management board at DTU proposed a change in the university's budget management that broke with the tradition of incremental growth completely aligned with existing academic traditions at the university. Instead, a proportion of the new budgets could be negotiated to support the creation of new units of research and teaching that would attend to current environmental and social concerns (Interview JH, 2013). Due to this development and the students' influence, the Department of Ecology and Environmental Education (Miljølære) was established. *It was the students who asked for Miljølære. It was then when students had something to say, had influence* (Interview KC, 2013).

Established in 1978, the Department of Social Science (Samfundsfag) aimed to provide engineering students with a better understanding of technologies' role in society. The initial role of this new unit was to introduce additional courses to the general modular structure of the educational programs, but not to organize new special programs and specializations within engineering. The research basis were disciplinary; one combined ecological perspectives with assessing chemical pollutants and climate change issues, while another brought sociological and economic perspectives on technology into engineering. The novelty of these initiatives is that they enforced demands and challenges articulated in the broader societal discourse over engineering education; and in this way, they departed from tradition: they challenged the instrumental engineering fields.

The two new departments (Dept. of Ecology and Dept. of Social Science) introduced new codes of meaning to engineering education that were not present within the existing departments and the dominant engineering domains of practice. The one was the crosscutting concern with environment as ecologies that also impacted climate, going beyond the separation in traditional media of pollution: water, soil and air. The other was the engagement of engineers through technologies with the social structures of society. These academic units grew and matured during the 1980s.

A number of new disciplinary courses emerged from these new departments. A specific requirement called the AMS points, equal to just a half-semester course load, was added to the modular structure and motivated engineering students to take a number of courses within the field of environment and social science. While the title of the Social Science department does not at first point to environmental or energy issues, the department soon became involved, not only with social impacts of technological change, but also questions of technology governance and economic issues in relation to pollution and resource use.

A NEW ENVIRONMENTAL ENGINEERING PROGRAM

An initial step towards creating a new educational program in Environmental Engineering was taken in the mid-1980s. It was initiated by the former pro-rector, because *we thought of doing something more formal and organized. We structured some lines of study, which were more aligned with students' needs. This was the background for structuring something in relation to environment education* (Interview KC, 2013). Even though there was a *conflict between the technicians and the more societally oriented* (Interview KC, 2013), the decision was made to establish the new Environmental Engineering program in the renamed Environmental Department, which had a long history originating in the traditions of sanitary engineering, water engineering and soil pollution. The new program was launched in 1987 and was headed by a professor in engineering geology who was appointed in 1983. Besides teaching geology, his research was focused on the contamination of soil and water sources. The preparation of the program included difficult negotiations about what should be included and not included in the curriculum.

The main aim of creating the program was to structure some of the activities and courses already framed by a science-based understanding of engineering: *The art was to combine these (existing courses)* (Interview AW, 2013). This resulted in a focus on the physical environment (nature out there), and issues such as ground water pollution, chemistry, geology and waste management were given priority. The aim was to educate engineers who were better at exploring soil as well as surface and ground water and cleaning the waste water. They should have a background in natural sciences and at the same time be able to solve specific environmental problems.

The departments involved were dominated by the code of meaning that implied an interpretation of the environment within a natural science conceptualization. The management and societal perspectives on the environment remained at the margins in the environmental program, because they were perceived as not belonging to the core of engineering competences. *Maybe we should have given more space to other aspects such as planning, but I don't think we were ready to take that step at that time – it was not considered to be really engineering* (Interview AW, 2013).

This meant that teaching covering societal and planning issues remained courses that the students could choose as part of their AMS points. But also teaching within renewable energy remained outside the environmental engineering program. This also meant that students, scientists and professors who did not subscribe to a specialized program on the environment, but rather to understanding the environment as part of broader societal issues, problems and developments were excluded from the negotiations regarding the Environmental Engineering program.

OTHER INITIATIVES AT DTU

Parallel to these institutional responses, questions concerned with the lack of integration and impact of societal issues and challenges on engineering competences led to the creation of additional but more temporary units (centres), which took specific topics under scrutiny in an attempt to build new interdisciplinary approaches as alternatives to the departments' single-discipline portfolios. The two most important initiatives during the early 1990s were the Interdisciplinary Centre (Tværfagligt Center) and the Technology Assessment Unit (Initiativet for Teknologivurdering).

The Interdisciplinary Centre was mainly concerned with food contamination in the production process, new strategies for organic food production, and the overall pollution from industry by examining the lifecycle of materials and products. Its members promoted a comprehensive view of the environment and thus advocated educating engineers in the principles of ecology and organic food providing courses based on this perspective. During the 1990s, these scholars also developed courses, research projects and activities in environmental management, cleaner technology, and life cycle assessment. The Technology Assessment Unit was especially instrumental in introducing Science and Technology Studies (STS), including new approaches to understand innovation, the history of technology and the relation of technology to society and nature; and in this respect also the study of transport systems and hygiene as well as the foundations of engineering knowledge and practices.

In the late 1980s, DTU was inspired by the first year's basic education established at Aalborg University from 1974 to organize the first years' curricula in topical teaching packages, still maintaining the modular and elective principles of the education programs. One of these packages focused on environmental issues. Another focused on energy systems and renewable energy (the Energy Package), offering students a coordinated set of courses and a project assignment that focused on energy issues. This new model for the introduction to engineering was terminated after some years (Interview MG, 2013).

During the late 1980s and early 1990s, a different approach to the environment began taking shape at DTU. Due to frustration over the lacking effect of the enforcement of the environmental laws introduced in the 1970s, a number of professional engineers, consultants, regulators and engineering researchers in Denmark and elsewhere engaged in developing new codes of meaning related to the scope of environmental engineering. They began shifting the focus from pollution and emissions resulting from companies' production activities, to the origins of these pollutants in the whole production process, and how these processes and practices could be improved. A whole academic and social movement was developed around the concept of Cleaner Technology, and numerous projects and evaluations were carried out at both DTU and AAU, funded by the Danish Environmental Protection Agency (DEPA) (Interview MSJ, 2013). The most significant project in terms of funding was EDIP (Environmental Design of Industrial Products), which covered specific research activities such as Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA). Due to the new focus on industry and management, these topics were developed at the Department of Production and not the Department of Environmental Engineering.

In addition, topics of environmental management and environmental economy were developed at the Department of Technology and Society (a merger of the two temporary units and the Social Science Department). The department provided scientific support to these new and often more interdisciplinary course activities, which integrated technical and social science perspectives. The department also developed a professional, part-time Master of Environmental Management (Teknisk Miljøledelse), which was launched in 1995. The aim of this program was to provide an education in environmental and health issues for employees with more than five years of experience in industry and governmental institutions (Interview JH, 2013).

Summing up, at DTU all the activities related to the old sanitary engineering research group on water provision and wastewater treatment became over time the core of the Environmental Engineering Department and its education program. Other activities, which addressed environmental issues as an integral part of production, organizations and society at large, remained outside the framework of the Environmental Engineering program. Courses like Environmental Management, Environment and Society, Environmental Engineering in the Tropics and many others became available to students; however, these courses were electives and never a core part of the Environmental Engineering program at DTU.

The perspectives of environmental management, product design, life cycle assessment and production were further developed within the programs of mechanical and production engineering. In addition, the perspectives of renewable energy were excluded in the Environmental Engineering Program. The explanation for this seems to be that environment is translated into being 'the nature out there'. This reflects the strong impact of existing codes of meaning maintained through the departmental organization of disciplinary knowledge. While the main focus on environmental issues remained within the framework of pollution (especially water-related), some new field of engineering concerns and domains of practices entered the realm of production and management engineering. As a general concern, the environmental discourse remained a topic for specific courses and a single, specialized educational program, but it did not enter the engineering educational programs at large as a crosscutting subject that was first introduced with the Department of Ecology and Environment. A broader ecological perspective did not survive as a separate department and even not as a prioritized disciplinary topic. Nor did the broader focus represented by the Social Science Department on societal perspectives of technology survive. These subjects, which had a crosscutting perspective linked to specific engineering challenges and competences, appeared over time to become subsumed into the perspectives established within specific codes of meaning related to engineers' instrumental problem solving. The actual result was that these new departments were not able to survive at DTU in the longer run. Instead, these new groups of researchers and their teaching were re-located into more well established fields of engineering such as on the one hand, management and product development with a focus on industry (private sector), and on the other, the handling of pollution and waste water in relation to public works (public sector) and engineering consultancy and construction. Still, a few general courses about the role of engineering in society were maintained to raise environmental issues, thus demonstrating that they are a general concern for engineering.

Our argument is that the tradition of disciplinary dominance was re-enacted at DTU as the code of meaning for engineering, as the science concerned with measuring and modelling natural resources and impacts was successfully up-scaled. In contrast, the codes of meaning related to social issues were located within the perspective of management or remained as single elective course activities that remained at the margins of the formal engineering curricula.

ENVIRONMENT AND PLANNING AT AAU

Due to several substantial differences in the histories of AAU and DTU, their developments have differed but are also in some aspects complementary. While DTU has been a school for engineering science and a research university with a long tradition (founded in 1829), AAU is a relative young university (founded in 1974) with a full academic program, though dominated by the engineering faculty. AAU combined both the spirit of the social and environmental movements from the beginning of the 1970s with the disciplinary traditions of two existing polytechnic institutions: the Engineering Academy and the Polytechnic School of Aalborg (Christensen, 2000).

The founding idea was to expand access to and capacities of universities by building new regional universities that also provided academic educational programs with a different pedagogical approach, including a stronger focus of the educational training on outreach to society and professional practices. When completely new universities were started, the Danish student movement used the opportunity to become involved in changing the academic educational tradition with its focus on lecturing and disciplinary knowledge. This resulted in strong influence on the visions of AAU and its learning principles – an influence that later also lead to improvements and changes at DTU, as illustrated in the previous section (Interview JH, 2013). Four characteristics are salient in this respect: (1) interdisciplinary approaches were encouraged from the beginning; (2) educational programs included a problem- and project-based learning concept (PBL); (3) programs started with one year of basic education for each faculty; and (4) the structure of departments was from the beginning organized in cross-disciplinary units that were supposed to evolve through organic changes and support interdisciplinary aspects of engineering education and research, as well as interaction with other academic fields. In terms of engineering education, all these aspects provided Aalborg with a competitive advantage in relation to producing business- and practice-oriented professionals to feed into the larger industries in Jutland and Denmark as a whole. After an initial period of scepticism toward the new learning concepts, employers in Danish industry welcomed the graduates from AAU.

Like many other young universities, the educational practice at AAU in the 1970s was to award engineering degrees with specializations in different topics according to students' choice of project work. Thus, it was possible to earn an engineering degree with specializations in such various areas as Indoor Environment, Energy Planning or Environmental Technology, while the classic engineering programs in Sanitary Engineering and Energy Technology also continued to exist.

The Department of Development and Planning at AAU was established in 1974. It hosted mostly engineers working on issues of physical planning, including Surveying. With the founding of AAU, this was moved to Aalborg from the Royal Agricultural and Veterinary School in Copenhagen for the deliberate purpose of adding social science perspectives to the hitherto rather technical curriculum. This was a result of the Danish municipality reform in 1970 and the subsequent legislation on spatial and infrastructure planning (Christensen, 2000).

With time, this department became more interdisciplinary and inclusive, especially with emphasis on a more comprehensive approach to planning in the fields of environment and energy with focus on the needs of both industry and government. Its roots in spatial planning had been setting its course with an emphasis on the role of legislation and public sector planning; consequently, it has played an important role in grounding the codes of meanings established, also when it comes to the variety of new topics that were taken up by the department in the following decades.

From 1980, changes accelerated as the one-year basic education in engineering at AAU aspired to a crosscutting introduction to issues concerning the role of technology in society and the environmental challenges. These topics were formally part of the curriculum from the university's very first days, but were most often secured through the students' choice of topics that required a societal perspective for their project assignments. To support supervision and provide introductory lectures, new staff members were employed who were competent in these emerging topics. As we found at DTU, the technical disciplines at AAU took up new technical issues and priorities following the emergence of new environment and energy technologies. This also implied a broadening of the classic idea of planning, from its focus on land use, cities, and infrastructures to more specific topics related to the emerging societal challenges from environmental pollution, water use issues, cleaner technologies in industry, and new renewable energy technologies and systems.

By institutional design, the Planning Department became fertile ground for the up-scaling of new codes of meaning in relation to the issues engineers should address as professionals. These new codes of meaning included a stronger mix of technical and social issues as planning became increasingly understood as the capacity of engineers to influence decisions and projects in established and emergent institutions, rather that just providing technical support.

The open structure of large departments made it possible to establish new disciplinary groups such as FATS (Faggruppen for Teknologi og Samfund) in 1982. This group was instrumental in organizing the introduction to issues concerning the societal use of technology and the impact of technology on society and environment (Interview AR, 2015). The argument was that *... without a critical reflection of society it is not possible to explain the exploitation of humans and nature that the development and use of technology leads to ...* (Müller et al., 1984:21).

Teachers and researchers in the new department of planning, as well as at the existing more classic department that focused on sanitation engineering, related closely to and worked on issues affecting the local society and the municipalities in North Jutland, in line with AAU's outreach principles. These topics included agriculture processes; use of fertilizers and pesticides; contamination of local lakes, rivers and fjords; heating of houses, offices and shop floors, and indoor climate in general; infrastructure for water provision, wastewater and solid-waste treatment; and many others (Interview KI, 2013). Because the teachers and researchers worked on such problems, and the students developed their curriculums around these problems every semester, the students became engaged in practice-oriented studies/research that also included consultancy and client-related work experiences. In this way, the traditional separation of teaching and research disciplines from engineering practice domains was to some extent overcome – or at least reduced – through institutional design and an improved alignment between societal priorities and engineering education.

This meant, in turn, that Aalborg graduates are appreciated for their capacity to search for and identify new knowledge and solve problems, rather than for being particularly well versed and established within traditional academic and engineering disciplines (Interview TP, 2013). This has also fostered their entrepreneurial capacity and their ability to step into the practice of engineering firms and consultancies more easily than is often the case with new engineering graduates. Still, some initiatives that grew out of the engineering school that pre-existed at the university also had an influence in maintaining a focus on wastewater treatment with the classical technical hygiene perspective, as well as energy educational programs focusing on specific types of energy technologies and their optimization. In these parts of the AAU engineering programs, the pedagogical reform has provided understanding of contemporary challenges and practices within existing engineering endeavours.

During the 1980s, two different strands of engineering educational programs developed. On the one hand, there were the research groups concerned with the technical aspects related to energy and the environment, with focus on indoor climate, sanitary systems, energy technologies, and environmental technologies. The focus in these programs was on technical issues and on the provision of services or end-of-pipe solutions, as in the case of wastewater handling. These programs followed an engineering science tradition, but focused on new challenges like renewable energy technology and low-energy buildings.

On the other hand, the scholars at the Department of Development and Planning became concerned with urban, energy and transportation planning. In both cases, engineering students met the same core engineering topics, including mathematics and physics (Interview AR, 2015). Thereafter, during their graduate years and in what is equivalent today to the master degree program, they developed special competencies within the fields that research groups could support.

A restructuring in the department also reflected the focus on planning. In 1986, the Energy and Ecology group was established as a spin off from the FATS group and new staff was hired to meet the demand from growing numbers of students. Later, in 1989, the Cleaner Technology group was added (Handberg, 2014). The creation of the Energy and Ecology group reflected the emergence of grassroots-based experiments with renewable energy; the establishment of the first wind turbine industries resulting from energy crisis in 1973; the critique of nuclear power; as well as the involvement of academics from AAU and DTU since the mid-1970s in alternative energy strategies. This development is illustrated by the first alternative energy plan for Denmark from 1976 (Meyer, 2000; Sørensen et al., 1976). The Cleaner Technology group reflected the changes in environmental governance that led to law enforcement to engage companies in proactive environmental protection. It was also engaged in turning government's cleaner technology focus from industrial processes to an increased focus on product regulation and design standards, including energy efficiency and reduced material consumption and pollution.

In their own understanding, many of the educational programs within the engineering science tradition are interdisciplinary, since they deal with several different engineering disciplines and in this way apply a solution-oriented approach that mirrors how the problems are perceived in the practical world. A general viewpoint is that working with problems from practical settings makes it necessary to work across traditional engineering disciplines and have an interdisciplinary understanding, both in the students' project work and in research. This viewpoint among the staff at the Department of Development and Planning goes further to emphasize the inclusion of societal perspectives and social science (and topics from the humanities) as a precondition for interdisciplinary research. Still, the grounding of research engagements and projects and the problem definition outset for students' project assignments must come from practical problems that transcend the traditional borders between disciplines at different faculties. This was reflected in the curriculum initiative taken in the late 1980s with the Planning Year, which received students from both the social sciences and a few different engineering programs, though mainly civil engineering. This is partly also the case with the specialization in International Technology Planning from the early 1990s, which gave students the opportunity to apply engineering knowledge in an international context – quite often in developing countries – taking up the use of cleaner technology in production or environmental assessments in industries and areal planning (Handberg, 2014).

Specializations within the single master program in Planning were especially due to the students' own projects. They included choices related to energy, transport, urban and environmental planning. Except for the Surveyor program that was run by the Department of Development and Planning, all other teaching obligations had until then been organized around course contributions, supervision and the mentioned specialization years. Further growth in the number of students, the adoption of the Bologna regulations, and the internationalization of master programs in Denmark encouraged engineering educators to attract more students. Thus, after a few years, separate master programs in Environmental Management (2000), Urban Planning and Management (UPM) (2000), Sustainable Energy Planning and Management (SEPM) (2004), and Sustainable Cities (2012) were developed. These programs were all taught in English and gave Danish bachelor students the opportunity to become part of an international study environment that in the beginning attracted students from several continents, and later on mainly from Europe, due to the restrictions of overseas students set by the Danish government. The significant participation of students from Asia and Africa in the beginning was also due to the established collaboration with universities in Thailand, Malaysia and South Africa within the Danish University Consortium for Environment and Development – Industry and Urban Areas (DUCED-IandUA), a program that also included the participation of the social science and environmental departments at DTU.

Until 2000, the Department of Development and Planning was related to both the Faculty of Social Science and the Faculty of Engineering, which formed a platform for several interdisciplinary research projects and educational programs between social science and engineering – also partly including traditional subjects from the humanities such as history of technology. Motivated by AAU management's wish to streamline the faculties organizationally and due to its size, the department was split into three in 2000. One group of academics went to the Social Science Department; a new Department of Architecture and Design was formed leading to the creation of a new educational program in Architecture and Design; while the largest group of academics continued in the Department of Development and Planning. These departments were now located solely under the Faculty of Engineering, although several research groups still had and recruited professors and other researchers with a social science background. Without changing the strategic focus on interdisciplinary cooperation, AAU reverted to more traditional divisions based on faculties (Handberg, 2014).

In short, the institutional design of AAU has provided a favourable selection environment for the up-scaling of different kinds of codes of meaning, especially those that are more interdisciplinary within the traditional engineering fields, but also across other disciplines. These institutional environments have also allowed the creation of programs that address energy and environmental issues from a planning and modelling perspective that includes aspects from social science in the educational programs and engages students to work with contemporary societal challenges. The dominant code of meaning has still been in favour of a societal and company-planning perspective, emphasizing assessment methods, governance and modelling as the disciplinary outcomes.

FINDINGS CONCERNING THE UPTAKE OF ENVIRONMENT AND ENERGY

At both DTU and AAU, the uptake of environment and energy topics has resulted from challenges to society recognized from the 1960s and onwards. Engineering has become a far more diverse and multifaceted endeavour. This development has led to the inclusion of a number of new educational programs and a focus on environmental challenges and energy issues of savings, optimization and modelling as new disciplines. At the same time, the institutional responses show rather different patterns and demonstrate the influential role of differing codes of meaning among the existing staff as well as the structure of educational programs and departments. These codes of meaning have staged the institutionalization of the challenges and the translation of the challenges into specific disciplines and matters of concern. Over time, they have also framed the translations of topical approaches as well as prioritized which formal, departmental structures were able to survive.

At DTU as well as at AAU, the energy challenge has been translated into a much stronger focus on renewable energy technologies like wind turbines, biofuels, solar cells etc. Parallel to this, a new discipline of energy system modelling has also emerged. Both cases replicate classic engineering codes of meaning assigned to technical objects and the use of models as the way to represent the need for coping with future changes. While an aspect of the focus on energy savings has become integrated into existing engineering disciplines within building construction, optimization of products, processes and machines etc., only at AAU has it survived as an interdisciplinary engagement that combines technical innovation with an engagement in household practices, policies and standardization. The early, common engagement in energy governance and public involvement is transformed at DTU into a focus on energy networks and systems, while the broader focus at AAU on planning and social sciences maintains an interest in understanding practices, ownership and involvement.

Different patterns, resulting from existing institutional structures and codes of meaning, have emerged concerning the translation of environmental challenges. DTU responded to the environmental challenge with a perspective based on engineering being divided between dealing with waste handling and the cleaning of water and soil based on public sector obligations and investments – classic emission-related topics. In addition to this, a rather different focus has developed in relation to improving processes in production and product development on other approaches dominantly relating to industry and the private sector. Existing disciplinary approaches from either chemical and sanitary engineering or from manufacturing and management engineering have proved to be dominant. The environmental challenges were translated into either a focus on pollution and waste handling (a reactive approach to environmental change) or a focus on improved products and processes of industrial production, followed by an involvement with environmental management in companies.

In comparison, while the translation at AAU also demonstrated the classic waste-handling dimension due to the dominant and already existing focus on societal planning and this field's interdisciplinary grounding, there has been a stronger focus on the social and governance processes. This brought the institutional and organizational aspects of environmental protection to the fore and gave priority to communication and strategic assessment tools like EIA (environmental impact assessment) and product standards and legislation. It also emphasizes the study of consumption practices and how these can be made objects of change, as well as a focus on reuse and recycling strategies.

SUSTAINABILITY CHALLENGES AND RESPONSES FROM DTU AND AAU

Sustainability, as a broader issue than environment and energy, has gained attention in research and teaching activities since the publication of the Brundtland report (1987). The notion has not least become a core part of the climate challenge debate with its deliberate take on multiple and conflicting goals covering not only the environment/energy challenges, but also balancing these in relation to local and global economic, social and influence/equity challenges. However, the meaning of the notion of sustainability and its conflicting elements is contested. When used as a qualifier in relation to educational programs, it is quite important to identify the more specific meanings applied and how they are translated into educational topics and practices.

No doubt most universities today have a reference to sustainability in their strategies and visions – sustainability has become a dominant discourse, an 'obligatory passage point', for universities to demonstrate their commitment to contemporary societal and climate challenges (Christensen et al., 2009). While this may be valued from a rhetorical point of view, it still does not tell us much about what this generalization and broadening of societal challenges does to engineering and educational training.

DTU's current strategy states: *DTU's educational programs must be designed so that sustainability is an integrated part of all programs. Also, all students have to accomplish curriculum elements that provide skills in innovation and entrepreneurship* (DTU, 2013). Similarly, at AAU, the new strategy states that AAU is *hosting a prestigious UNESCO centre for Problem Based Learning in Engineering Science and Sustainability* (AAU, 2015). In both cases, no further guidelines or learning goals are established for how to meet these visions. At DTU, there is already a glitch in the wording that turns the focus from sustainability to more classic engagements of engineering with innovation and entrepreneurship. Attempts to produce common guidelines for the 'integrated part' has failed so far, not least due to the concern with 'watering down the technical competences of engineers'. The result is that these topics tend to end as extra-curricular activities, for example at DTU in the 'Green Contest', where students can take study projects outside the grading system and present them to win a prize. At AAU, the expectation is that this obligation is covered by the introduction to PBL principles, which includes taking outset in societal challenges in the problems to be solved. In the current interpretation, this includes issues of sustainability – which at best results in current debates being reflected in the students projects, because these introductions have no room for further qualification.

Aside from these general but limited references to 'sustainability', this notion appears in the titles of a few educational programs. At DTU, sustainability appears only in one master program that focuses on 'Sustainable Energy', while environment still appears as mentioned earlier in the Environmental Engineering program title. This program has its focus on energy systems, and the reference to sustainability is motivated by the program's topical focus on sustainable energy technologies, which implies that the notion refers to features of renewable energy technologies: biofuels, fuel cells, wind turbines and thermal energy per se, due to their potential reduction of climate impacts.

At AAU, the master program in Environmental Management had its name expanded to include Sustainability Science (EMSS) after a couple of years in order to give more attention to the social dimension of sustainability. Another relevant example is the reason for using sustainability in the name of the Sustainable Energy Planning and Management (SEPM) program from 2004. Research and planning in relation to energy systems has for several decades been an interactive endeavour in Denmark, especially involving grassroots movements and authorities at the municipal and regional level, as well as ministries and regulatory bodies. Even the new trends to construct markets for infrastructure services build an interactive model of governance. Therefore, when the possibility to make separate master programs arose, educators sought a translation that captured this interactive character and chose 'sustainable energy planning and management'. At the same time, they opened their energy systems model focus to include institutional aspects of how the energy infrastructure is structured. In this sense, the use of 'sustainable' differentiated the Danish type of participatory planning from the strategic top-down planning, which is popular in other parts of the world. In addition, as already mentioned, the Department of Development and Planning has a tradition for substantial integration among levels and forms of knowledge and project work, which in many ways captures the spirit of what the journey towards sustainability is all about (Interview HL, 2013). In addition, a program in Sustainable Biotechnology was initiated with emphasis of biotechnical refining of substances and materials as the motivation for using the notion of sustainability. This again mostly refers to the environmental expectations related to the technology.

Recently, a new generation of engineering educators used a window of opportunity to develop an engineering master program in Sustainable Cities (SusCi) at AAU. The window was linked to an expansion of AAU with a new campus in Copenhagen. The program builds on the tradition of integrating knowledge from different disciplines bridging the social sciences and technology at the Department of Development and Planning. One of the arguments for the new program has been that independent planning activities in isolated sectors are not feasible in the long run. Instead, a cross-sectoral perspective must be developed. In addition, cities and urban settings as a spatial and institutional setting for research and integration have become more and more important – in general economic terms, and also in the literature on transitions to sustainability (Bulkeley et al., 2010).

During the process of designing and obtaining accreditation for the Master in Sustainable Cities, engineering educators underwent two critical moments. One was the very positive response from the panel of external partners that reviewed the proposal. The potential employers of program graduates were especially encouraged concerning the prospect of having engineers who are capable of integrating and working across sectors, as well as navigating municipal administrative bodies and national regulations, and being able to innovate institutionally and technically. The other critical moment was an inquiry from the accreditation bodies as to what made this an engineering program and not a social science program. The argumentation finally relied on maintaining that students, aside from receiving training in issues such as resource measurements, climate change processes and urban development, would also become technically competent in the development and use of modelling tools, such as life cycle assessment, carbon and environmental footprints, eco-design and energy system analysis. The Sustainable Cities program is based on a combination of courses presenting existing methods and metrics, including some of their disciplinary background. Its take on sustainability lies in the combination of topics and project assignments defined by the professional perspective of engineers working in cross-sector planning (Interview BVM, 2013).

A further step at AAU was the establishment of a new engineering program in 2013 with focus on Sustainable Design. At the core of this program is the inclusion of different societal actors who set the stage for sustainable change and broader transitions that challenge existing technological products, models and systems.

This provides the students with analytical tools to handle the uncertainties, the interdisciplinary and socio-material integration inspired by Science and Technology Studies, and new models and solutions they need as part of their engineering design work. While, the technical subjects' engineering core satisfies the demands set by the accreditation board these tend to abstract from the specific use contexts and conditions. Besides defining the project assignments, sustainability is addressed in courses focusing on product service systems, system design, business models, and extended design criteria, including the social and political dimensions of sustainability. Sustainability within this educational approach is as much a part of the design challenge as the technical products and systems.

DISCUSSION OF THE FINDINGS

Sterling (2001) suggests that there are four response strategies to sustainability in education: no response; accommodating response; reformatory response; and transformative response. The majority of engineering schools and institutions in the world that either ignore or deny the challenges of sustainability fall into the first category. Those who follow the accommodating response have either developed new add-on courses to their curriculum (Kamp, 2006) or have attempted to incorporate sustainability in existing programs without fundamentally changing their nature (Chau, 2007; Costa & Scoble, 2006). Reformative attempts have been made to incorporate sustainability in all university programs (Kamp, 2006; Mulder, 2006) and by issuing requirements for incorporating sustainable development in the education of engineers (Barry, 2007; Sterling & Thomas, 2006). Finally, a few institutions have attempted a transformative strategy in relation to sustainability.

These considerations are in line with developments in engineering for sustainable development. Universities meet the sustainability challenge at all levels, but neither strategies using a top-down nor a bottom-up approach are satisfactory in changing the practices at engineering research universities. Researchers and teachers cannot be motivated to incorporate sustainable development principles in their courses and research unless they develop a thorough understanding of its importance, and match their knowledge with considerable work on curricular development (Kamp, 2006; Mulder, 2006; Peet, Mulder, & Bijma, 2004).

Our analysis also differs from that of Holmberg et al. (2008) in distinguishing between internal and societal/contextual factors of resistance to change within engineering education institutions. Their analysis of three different institutions (Chalmers University of Technology – Sweden; Delft University of Technology – The Netherlands; and Technical University of Catalonia – Spain) shows that the incorporation of sustainability in curricular activities is the consequence of a mixture of strategies to deal with internal and societal/contextual factors at the same time. Our analysis shows that curricular development strategies fit the internal and societal/contextual practices of institutions differently. In other words, legitimacy is built and validated through different strategies, depending on the responses and curricula developed either in accordance with the existing paradigm or in pursuing a paradigm shift. As we have shown, both DTU and AAU have been loyal to their internal institutional paradigms and their established codes of meaning, but only AAU has departed on a long-term basis from the traditional, established science-based engineering and instrumental practice paradigm.

Kamp (2006) accounts for how Delft University of Technology in Holland has pursued a three-legged strategy for integrating sustainability in education: (1) a dedicated course for all students; (2) intertwining sustainable design in all regular disciplinary courses; (3) structure a specialization conducive to degree in each faculty. Kamp concludes that there has been relative success with the three strategies: *however, integrating sustainability fully into the curricula and changing the engineering paradigm requires support from leading scientists, lecturers and the university board. Therefore, without co-operation of the rest of the Delft University our efforts will not have a lasting impact*. In line with this reflection, our analysis shows a contrast: At DTU, these issues were 'squared' in a classical tradition for educating engineers. Therefore, no noticeable paradigm shift can be observed at DTU. Conversely, at AAU, a paradigm shift can be observed as environmental and sustainability issues have 'broadened' what is normally understood as training engineers and led to experiments with new kinds of interdisciplinary research and education. This has been facilitated in great measure due to the university's experimental character and to the fact that the whole institution is PBL-oriented.

CONCLUSIONS

In this chapter, we have accounted for the ways in which new societal challenges in the areas of environment, energy, and sustainability have been articulated in engineering education at DTU and AAU. In both cases, we have observed a slow and careful negotiation of legitimate spaces for curricular development, rather than a clean top-down or a clean bottom-up approach (Mulder, 2006). Two different institutional paths of development can be observed in Denmark's two most important research universities with engineering programs.

At DTU, since the 1970s, environmental challenges have been gradually, narrowed down to specific problems, solutions, indicators, and metrics that reflected already established codes of meaning coming from existing disciplines, which strengthened historically established domains of engineering practice. Two parallel developments can be observed: one emphasizing different environmental technologies, and the other focusing on production engineering and the management of environmental issues within a company-dominated perspective.

At AAU, environmental issues have evolved around a perspective of interactive planning, emphasizing the role of public regulatory institutions and consultancy. This in contrast to the focus at DTU on methods and procedures to be used in management companies. Both institutions have focused on the identifying sources and solutions to environmental challenges on the one hand, and on energy systems modelling of renewable energy sources on the other; however, the fields of professional application have evolved differently. While engineering programs gradually have addressed sustainability issues more comprehensively, AAU's focus on students' problem- and project-based learning (PBL), in close collaboration with companies and municipalities, has opened for more innovative approaches. We regard this as a 'broadening' development.

In short, over a period of several decades, environment and energy challenges have been taken up in engineering education through the building of new engineering tools and metrics. These encompass life cycle assessment, environmental assessment, modified design principles for a wide range of technologies, energy savings, new renewable energy technologies, and system models that integrate energy technologies and savings. In this process, the broader analytical take on these challenges through ecology and social science approaches has been marginalized.

We can observe the same happening in the responses to climate challenges and sustainability. The solving of open-ended problems resulting from taking action in sustainable transformation is mostly represented in strategic rhetoric, while only a few dedicated and specialized educational programs and even fewer courses have been established.

One obvious major challenge is the difficulty in building a sustainability metrics that can provide answers from the outset on how to assess design solutions. Sustainability as such is an open-ended and path-dependent valuation framework that may guide and inspire, but which evades the demand to become instrumental and predictive. Alhough this follows from the idea often presented in discussions of engineering education about the importance of dealing with real world, wicked problem identification is not the priority of engineering departments and faculty, where the dominant focus is on providing technological solutions to societal challenges.

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KAREN L. TONSO

5. ENACTING PRACTICES

Engineer Identities in Engineering Education

INTRODUCTION

Calling someone an engineer signals both their having an engineer identity and their practicing engineering, but such statements say little about the process of *becoming* an engineer, and less about the part engineering education might play in such processes. In the 1990s (in the US), engineering education had for almost a decade added a new learning setting to an already complicated curriculum of scientific, mathematical, and engineering-science offerings. Design courses provided opportunities for student engineers to work on teams for an extended period of time (usually a semester or two), to complete a project typical of industry or government engineering work, and to work with an engineer employed at the project site. Design courses intended to challenge what campuses conveyed about what an engineer might be and do, all of which suggested a fertile research setting for studying engineer identities and affiliated practices in an engineering education site, the focus of this chapter.

'Identity' evokes a wide range of social science conceptions (Tonso, 2014). For instance, some psychological researchers take in-the-person notions of identity (e.g., Erikson, 1968), while sociocultural psychology perceives of 'persona' as negotiated during interactions in a social space[1] (e.g. Mead, 2001). Criticisms exist for both. The former dislocates individuals from space and time, which the latter corrects by locating individuals in immediate social settings, an approach that often overlooks larger societal forces, such as race, gender, and social class. In addition, STS scholars highlighted the geopolitical aspects of engineer identity (Downey & Lucena, 2005). Different national circumstances influenced both the sorts of engineering given prominence and the educational preparation needed for these pursuits, which led to considerable cross-national variation in engineer identity. But, none of these approaches considered identity development as an enculturated process. In cultural anthropology, anthropologists conceive of identity development in historically persistent, communal ways of life (culture) (Holland, Lachicotte, Skinner, & Cain, 1998)

To consider an enculturated identity – one learned through community-based interactions – required anthropological conceptions of 'culture' to evolve. Early conceptions of culture commenced with notions about group life being fixed

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or static, often considering the cultural group isolated from external influences (Malinowski, 1922), but modern life seldom met these criteria. To account for societal structures (such as social class), cultural *reproduction* theorists conceived of "culture" in terms of individuals being the way they were because of being structured by societal and cultural forces (Eckert, 1989; Foley, 1990). But, this conception gave little room for individual autonomy (Willis, 1977). Further conversations about identity, autonomy, and enculturated learning led to cultural *production* theories: how individuals perceive of themselves while simultaneously studying how one's sense of self was worked out over time through interactions during everyday life and how identity might be framed (molded, worked on, or otherwise influenced) by both local culture and larger societal structuring of everyday life (Levinson, Foley, & Holland, 1996). This conception took better advantage of Geertzian notions of (local) culture, where culture implied how systems of meaning are learned during social interactions during everyday activities in a community with historical persistence. Such a conception of culture allowed anthropological scholars to pay more attention to individuals – notions of 'becoming someone' – within a local culture, without losing sight of the mutual shaping occurring between local culture and enculturated practices and personas (Holland et al., 1998; Lave & Wenger, 1991). In addition, this conception gave ways to ascertain to what extent local cultures shifted over time, whether they enculturated processes for stasis (an obdurate culture, such as the one revealed at the field site), or were malleable and enculturated processes for change.

Lave and Wenger's (1991) work, in particular, guided thinking about how student engineers might *learn* to be engineers and to do engineering. Lave and Wenger studied apprentices learning trades, such as tailoring and butchering. In these kinds of learning settings, apprentices fit into trades as novices who initially performed useful work of a rudimentary nature under the direction of a skilled tradesman, an oldtimer. Over time, through learning more complex tasks central to membership in the trade, apprentices moved along a trajectory toward becoming oldtimers. Lave and Wenger found that oldtimer identity captured the imagination of novices, and novice-oldtimer interactions proved central to becoming a member of such a community of practice, someone able to demonstrate a full range of understandings about practices in their community. They called this process *situated learning* and such groups *communities of practice*. In such communities, self, practice, and world are co-constructed, and learning becomes not so much acquisition of a fixed set of understandings, but a process that delimits how change occurs in a community.

> *If context is viewed as a social world constituted in relation to persons acting, both context and activity seem inescapably flexible and changing. And thus characterized, changing participation and understanding in practice – the problem of learning – cannot help but become central as well.* (Chaiklin & Lave, 1993:5)

Apprenticeship learning illustrates a contextual sort of learning, one where oldtimer members of the trades – present and interacting with novices – routinely demonstrate everyday community practices. At Public Engineering School, fieldwork reconnaissance suggested that design courses (described below) might be organized in ways to provide for situated learning in a community of practice, with engineer oldtimers, student engineer novices, and guided entry into the world of practicing engineers.

In what follows, cultural production theory and situated learning theory guide considering how engineer identity and engineering practice might be co-produced, in a local engineering education (campus) culture, amid the cultural history underpinning the site.

SITUATING THE STUDY OF PUBLIC ENGINEERING SCHOOL

The research underpinning the historical case reported in this chapter occurred in the US mid-continent at Public Engineering School (a pseudonym abbreviated throughout as PES). Typical of US engineering schools in the 1990s, PES incorporated design courses in their curricula to promote more industry-like skills, something the (US) Accreditation Board for Engineering and Technology (ABET) included in their expectations about a decade later. The design-course logic emerged in response to industry's call for engineers who could apply their academic-science classroom learning to real-world engineering projects, and a desire to diversify engineering graduates. In the late 1980s, women earned fewer than 16% of engineering degrees, when the rate of growth of women's entry into all science, technology, engineering, and mathematics fields had slowed (Jacobs, 1995). By 1995 women's numbers among engineering undergraduate degrees rose to about 18% (see Tonso, 2007:3), the current US plateau (ASEE, 2011). On the campus studied, however, women represented over 20% of all students (graduate and undergraduate) and about 25% of the first-year class. Thus, the campus considered itself a leader in adding design to its curriculum and in working to diversify its student body.

Part of the logic of including design courses emerged from an influential 1980s gender-difference argument (e.g. Belenky, Clinchy, Goldberger, & Tarule, 1986; Gilligan, 1982), which suggested that women differ from men (and have better social, teamwork, and reading and writing skills). The gender-difference argument suggested that design courses not only enhanced engineering education and taught skills all students needed, but also incorporated women's "natural" skills, which would make engineering education a friendlier place for women. Though some argued that solutions grounded in gender-difference theories overlooked the culture of disciplines like engineering education (e.g. Eisenhart & Finkel, 1998; Tonso, 1997), a gender-difference mindset grounded design course justifications. Public Engineering School (PES) typified stand-alone, selective engineering schools of the time, and its study (Tonso, 1997) diverged from popular thought to study the culture of an engineering campus.

The ABET-accredited engineering curriculum at PES paralleled that seen at a large number of US engineering education institutions of the time, including both conventional engineering courses and design courses (89% and 11% of coursework credit hours, respectively). Conventional academic-science courses covered calculus, Newtonian and quantum physics, physical and quantitative chemistry; engineering-science courses: statics, dynamics, fluids, thermodynamics, strength of materials; and sub-discipline engineering-science courses. Taken together these greedy courses contain fast-paced delivery of complex mathematized knowledge, with one right answer to coursework questions. Success on pencil-and-paper homework sets and exams fed class rank and grade-point averages that resulted in selection for awards and honours, plus preferential treatment in initial hiring decisions via campus-supported systems. In all majors (Tonso, 2007), courses and their sequence were overwhelmingly dictated and not chosen by students. Pre-requisites for senior-level courses interconnected tightly with prior courses. In addition, one course in every major served as a gatekeeper for most third- and fourth-year courses, allowing very little flexibility. Lack of success in a particular course (especially the gatekeeper course) delayed graduation.

In contrast, design courses provided a hybrid learning setting where knowledge learned in conventional engineering coursework putatively combined with "real-world" or "industry" engineering practices. According to campus design advocates, design courses explicitly challenged the conventional *academic-science* notion of engineering practice, especially by incorporating both technical and non-technical, context-specific constraints to frame selection of a proposed solution from among multiple possibilities, and by requiring considerable social interactions and non-technical components to complete projects. Campus insiders called this form of engineering practice *design engineering.* First-year students completed a common project, while sophomore and senior student design teams worked for government and industry clients, and each had a client contact. Senior team contacts were industry engineers with several years of experience.

Students took two semesters of design in their first and second years, and a one- or two-semester course as seniors. During project teamwork students were encouraged to develop multiple approaches to their project, usually stated as a dilemma. For instance, the dilemma for one of the sophomore teams read: How should a town with many historic buildings respond to the Americans with Disabilities Act? Faculty expected students to examine different approaches using a list of constraints to select a best solution from among many possibilities. Design courses included regular teamwork, in-class lectures from faculty about how to meet coursework requirements, and periodic graded items. Unfortunately, graded items rarely encompassed many of the activities central to the *doing* of engineering. Faculty overlooked observation of teamwork and review of substantive engineering computations or fact-checking, and instead focused on student-produced items typical of pre-design-reform technical-writing or -drawing courses, such as copy-editing individual and group written work, evaluating oral-presentation minutiae according to guidelines for length, presenter dress, and readability of overhead slides, or checking formatting specifications for computer-generated drawings.

Grades on drafts of written proposals, oral presentations, plus computer programs and mechanical drawings for non-project purposes, predominated in early design. Only at the senior level in the final report did faculty read reports with an eye both to writing mechanics and engineering expertise.

Many aspects of the design courses incorporated, rather then re-visioned, historic practices. For instance, early design experiences incorporated content material nearly identical to parts of the campus curriculum dating some 25 years earlier – descriptive geometry and technical drawing, computer programming – with a prior technical writing course changed only by shifting to teamwork reports. Stasis also appeared in other activities. For instance, a design faculty alumnus (from 25 years earlier) commiserated with a first-year student about grading on a drafting quiz. Both had lost the same six points (and a letter grade) for not drawing lettering guidelines for their names on each page. Though touted as a major curricular reform, such vestigial traces of practices from the late 1960s suggested design's marginality on campus.

During fieldwork I began to wonder: What do student engineers *make* of becoming an engineer at PES, especially when viewed from the vantage point of engineering-design teamwork where nonconventional learning might be promoted? How might students talk about one another as engineers, and organize this talk? And what does this disclose about relationships and affiliations among engineer identities and forms of engineering practice?[2]

NOTES ON FIELDWORK

The research project took an (ethnographic) anthropological view. In courses enrolling students from all sub-disciplines, over the course of four semesters – one at the first-year level, one at the sophomore level, and two at the senior level – I followed students learning to be (becoming) engineers as part and parcel of their learning to do engineering. From 1993–1996, using common ethnographic research practices, I joined seven student teams as an active team member (two at both the sophomore and senior levels, three at the first-year level; comprised of 33 students – 15 women and 18 men, guided by 11 faculty members). Here I collected field notes in all in- and out-of-class team meetings, visited client sites with teams, collected artifacts (things used and produced in students' design work), and performed two ethnographic interviews of all students and at least one interview of each faculty advisor. In addition, I surveyed 274 students about the differences between design and non-design courses,[3] and performed an analysis of curricular structures (Nespor, 1990).

This is a coming-of-age-on-an-engineering-campus story of insiders becoming engineers at PES. As I will argue below, on the one hand two identity strata emerged, each affiliated with a different set of engineering practices, and on the other hand students "interpreted" engineering practices through local-culture-specific identity frames of reference to infer identities from practices, to connect practices to identities. Let me take up identities and practices in turn, before discussing their coproduction.

PES ENGINEER IDENTITIES

After hearing students use a large number of terms to refer to one another as engineers on campus, how students organized campus engineers came to light via a queue-sort research strategy (e.g., Holland & Skinner, 1987). Students' ways of organizing the terms also signaled power relations on this campus, and engineering affiliated practices emerged from their descriptions of the terms and categories.

Engineer Identities

Three central engineer identity categories emerged capturing students' organization of the 36 most frequently used terms (out of over 100 elicited) (Figure 1): Greeks (so named because of affiliations with fraternity/sorority "greek-letter" societies); Academic-Achievers; and Nerds. Students combined Greeks and Academic-Achievers into one category that they called 'the Over-Achievers.'[4] Within each category, student engineers characterized two subsets: "normal" engineer identities whose behaviors were acceptable (solid outlines), and unacceptable engineer identities for those who 'went too far' (dashed outlines). First-year students knew very little about identities, but seniors had extensive engineer identity vocabularies, documenting that the learning of the terms was part of their engineering educations.

To students, identity terms that fit among normal Greeks conveyed shades of meaning implying not only that normal Greeks led and participated in campus social life (organizing and attending dances, as well as seminars and workshops for improving campus life), but also garnered the attention of faculty and administration through academics, leadership, or sports prowess to become stars. Student engineers here had 'outgoing personalities [and] take leadership positions on campus, the real doers'. But fraternity and sorority membership required high academic performance and student engineers affiliating here were also known for giving significant attention to their academic standing. In field site observations, student engineers thought of as Greeks demonstrated only minimal capabilities understanding the circumstances of the locale central to their design project (which will be discussed below).

Students understood normal Academic-Achievers to be students who became stars on campus because they placed grades and academic standing above other activities, and because campus reward systems noticed these endeavours. Such a set of on-campus engineering practices gave prominence to academic-science activities typical of conventional classroom schoolwork. Student engineers considered to be Academic-Achievers 'have the talent to do well [academically] and want to capitalize on it'. Similar to Greeks, Academic-Achievers did not understand the import of material objects in their field sites. For instance, in a visit to the senior

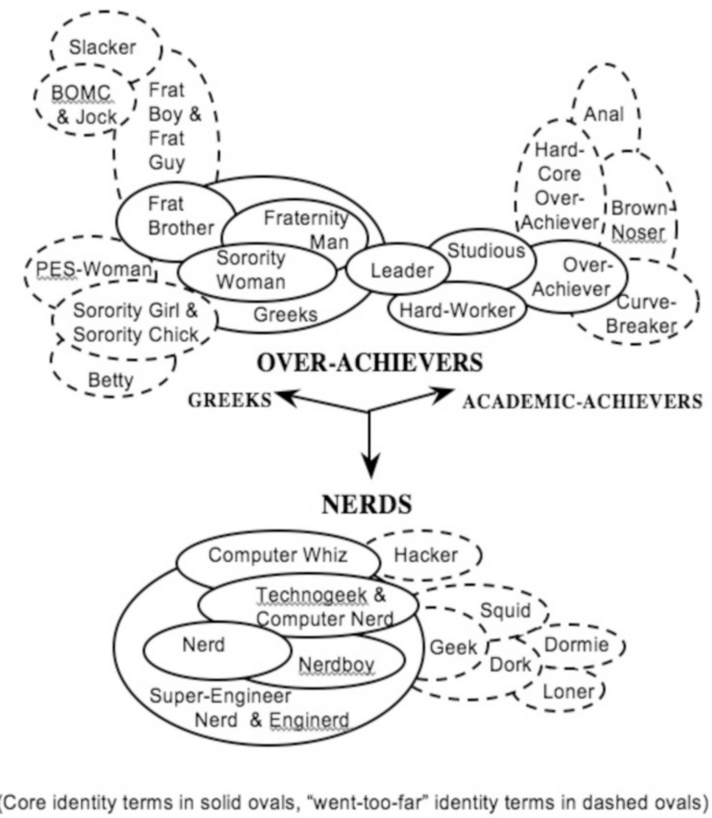

Figure 1. The identity terrain at PES, a map of PES engineer identities

Mercury Team's power plant, a campus star failed to notice important clues about information required to select a condenser, his part of the team's design project.

However, Nerds demonstrated a more expansive set of understandings. While not eschewing the academic-science side of campus life, Nerds also focused on making sense of academic-science understandings in real-world settings, something outside faculty grading practices. "[Nerds] figure out the theory and the math behind it and you've got all the practical knowledge, so he could build just about anything." In project sites, Nerds crawled over plant settings, worked out piping and equipment monitoring, and connected conventional coursework to aspects of their project. Nerds exhibited behaviours consistent with heterogeneous engineers (MacKenzie, 1996), fitting current ABET standards not only for understanding mathematical, scientific, and engineering principles, but also other key areas included in ABET. These areas encompass: designing and conducting experiments; analysing and interpreting data; matching a design to a particular context; [valuing] working on multidisciplinary teams; problem identification, formulation, and solution; communicating effectively; understanding the impact of engineering solutions in light of contemporary issues; and using tools needed for engineering practice (ABET, http://www.abet.org/eac-current-criteria/ downloaded July 27, 2012).

Senior student engineers took these terms and affiliated engineering practices for granted as if they represented a "reality" on campus, when in fact they represented the normality. In their naming of the categories and the partitioning between acceptable and unacceptable kinds of campus engineers, students described on-campus relations of power.

Encoding Power in Engineer Identities

According to student engineers, Over-Achievers were "over" others, as was its affiliated academic-science engineering practice, signaling primarily that campus authorities rewarded these (as described below). Students used identity terms as an interpretive frame for characterizing the actions of others, as a guide for making decisions about their own actions (and inactions), as a normalizing technology to chastise unacceptable behaviors, and ultimately as a way to delineate belonging as an engineer on campus, which raised prickly questions about women's (and others') legitimacy as engineers at PES.

Through participating in the life promoted by the campus curriculum, faculty teaching practices, and the sociocultural production of success and excellence made evident in grading practices, award distributions, and scholarship recognition; engineer identities embodied engineering practices and these encoded variations in engineering expertise, gender, and power as made evident in students' social interactions. For instance, as students went about their everyday lives, they made decisions about how to act, taking into account affiliating, or not, with campus-preferred ways of life. In time, students learned to think of types of engineers in terms of being Greeks, Academic-Achievers, or Nerds, and to characterize other students (those considered to belong) using the engineer identity terms. In addition, students deployed engineer identity terms in social control routines to police inappropriate behaviours. Thus, getting a high grade on a test with a low average prompted a fraternity brother to call you a curvebreaker (going too far with academic achievement), while studying instead of going out for a beer resulted in being called a nerdboy for paying too much attention to coursework requirements. Through such conversations, student engineers learned to think about how their actions would be taken by others, that is, how actions were *given meaning* on campus, how individuals were *identified* as belonging (or not). As such, engineer identity proved more complicated than mere presentations of self (identifying with engineering) and became a continuously produced notion of individuals acting in context (demonstrating engineer identity), where actions were given meaning, framed, and mediated by cultural knowledge (a recognition process of being identified as belonging in engineering).

Furthermore, the terms signalled the normative masculinity of the campus culture (Tonso, 1999), which became apparent in conversations with senior students about how they identified their teammates. Here, senior teammates identified men teammates using the same identity term, and gave illustrative examples to back up their characterizations. However, they struggled to find a term for women teammates who were not among Greeks. These women – whose teamwork activities seemed consistent with men Nerds or Academic-Achievers – left student engineers at a loss for words. Martin illustrates the kinds of explanations given for this. After describing his teammate Marianne's engineering expertise as like his own (design engineering, fitting among Nerds), Martin explained his difficulty thinking of Marianne via the engineer identities he had so easily used for his men teammates:

> *You don't think of women as that [Nerds], I guess. 'Cause, at least at this school, I think guys here so much appreciate that a girl chose to come to this campus that you're just like, "Great!" There are so many guys that you can say: "This guy's a nerd."*

Asking Martin to "identify" his teammates tapped his cultural knowledge about PES engineer identities, where a vacuum existed for trying to think of women who did not fit among Greek social over-achievers. Campus engineer identity made (produced) women – who otherwise seemed to fit as Nerds and Academic-Achievers – invisible (as engineers). Viewed using cultural production theory, then, the way students deployed the identity terms served to produce campus culture and this example illustrates how campus culture was preserved/produced as masculine, and women were produced as appropriate only among Greeks, the category considered "social," but not among the two categories thought of as "technical," mirroring societal expectations (Faulkner, 1994, 2007).

Two societal ideologies reached into the campus way of life, and became evident in the identity terrain and in design team interactions, and these also framed student engineers' sociocultural productions (Tonso, 2006). Gender status became apparent in a hegemonic form of masculinity elevated in Over-Achiever identities (authoritarian, competitive, often dismissive of women's engineering capabilities) that rose above Nerd masculinities (communal, shared leadership, respectful of women as technically competent teammates), and both of these masculinities rose above femininities. Academic-science prestige became evident in the hegemonic form of practice – academic-science engineering – aligned with campus proclivities and practiced by Over-Achievers, and it trumped design engineering practiced by Nerds.

In such a milieu, student engineers altered their own actions to be identified as acceptable sorts of engineers, often by hiding or amplifying certain subjectivities. Some students suppressed aspects of themselves and came to seem less than they were, while others accrued undeserved accolades and came to seem more than they should have been. For instance, Martin (Nerd) not only demonstrated robust skills facilitating group interactions in the Sludge Team, but he also created a welcoming social environment at his apartment, where he provided team-members' preferred snacks. Most of the team noticed his skill facilitating the team meetings, and thought it normal engineering behaviour. But, they thought his having their favourite potato chips was unusual, something an aunt or mother might do, feminized behaviour. Here, Martin deployed both masculine and feminine aspects of his engineer identity, but he carefully hid his feminine aspects – and his acceptance of women – from other students in the design course whole-class setting. Students with empathy for gays and lesbians, who expressed concern with the homophobic campus climate, suppressed their ideals in the presence of comments made by men who inhabited the hegemonic engineer identity positions in the larger campus community. They thus came to seem less than they were.

Others students used their status to promote their own interests, by undercutting teammates' contributions and accruing undeserved accolades. For instance, for the benefit of their faculty advisor, Pete (a "went-too-far" Over-Achiever) routinely mischaracterized a hard-working Nerd teammate as a slacker (someone not contributing to teamwork) and frequently took credit for teamwork contributions made by others. But, teammates never challenged Pete's actions, leaving the faculty advisor to accept Pete's representations, and consider Pete more capable than he deserved. Pete's teammates told me that challenging his version of the team's work "wouldn't make any difference." Their not (re)acting, because to do so would put them at risk of hassles from Pete or indicate that they were "not a team player," contributed to Pete's version of normality sticking, and benefited his reputation. Thus, "star" students could seem to be more than they were.

PES culture thus encoded significant inequities, while maintaining "we're all equal engineers" (Tonso, 2007). "Students learned to take these terms (and other encoded detail) as cultural fact and deployed them to make sense of how their world was *supposed* or *imagined* to work, even [in the presence of contradictory] … empirical evidence" (Tonso, 2007:234). "This collective ability to take imaginary worlds seriously … is the magic that anthropologists have tried to capture in the concept of culture" (Holland et al., 1998:280).

But, design projects intended to muddy up the campus way of life by offering opportunities for student engineers to interact with industry- or government-employed engineers, to establish opportunities for novice engineers to work with old-timer engineers and learn about the world of practicing engineers.

INTERACTING WITH AN "ACTUAL" ENGINEER

In contrast to the rich vocabulary about engineer identity produced and reproduced during cultural meaning-making on campus, students used only one term for referring to different kinds of engineers in workplace or industry settings: "actual" engineer. The case of the senior Sludge Team provides the best example from the research. This team met regularly with Curtis, their client contact, and interactions seemed illustrative of the old-timer ideal advanced by campus design-course advocates.

Curtis, an engineer-manager, served as the primary source of information about the corporate way of life where the team situated their design project. In almost every interaction, Curtis gave chalk talks about how the plant functioned, replete with detailed sketches of major equipment. He routinely shared what he knew about plant operations, gave students full access to the plant, and arranged for their using the plant's conference room for weekly team meetings. Most of the meetings with Curtis were akin to staff meetings where team members discussed progress on different aspects of the project with Curtis and sought his advice. On several occasions though, Curtis moved into the plant: to give guided tours, to explain the physical layout and operational characteristics of the plant, to discuss several ongoing issues where the team might make a contribution, to illuminate important plant features germane to their project, and finally to install their data-collection instrumentation (the focus of the example used here). Thus, with considerable standing in the company and the plant, he served as a consultant to the team, gave the student engineers considerable latitude to identify and develop their team's project, and smoothed the team's way in the plant. One particular visit to the plant illustrates the interactions between Curtis and members of the team, and provides a look at students' engineering practices (Tonso, 2007).

When the time came for the team to install and test their pressure-measuring apparatus, Curtis performed the installation, as well as communicated with the plant operator. Curtis would complete the installation and manipulate plant conditions to ensure the newly installed equipment functioned properly, with team members monitoring progress in the control room, then incorporate the equipment into the plant. Notice how Martin and Marianne make important observations about data they are gathering, and how Curtis interjects salient technical language to name, and explain, plant events (4-4-95 plant site field notes):

While Martin waits for the others to install the calibrated pressure gauge, he explains to Nate that the pressure transducers need a power supply to get the signal from the basement to the control room. The operating specifications mandated 10 to 20 volts, but on further inspection Martin believes this may not be enough voltage. He increases the power supply to over 25 volts. The phone rings and the operator answers it.

Operator: *They're reading 82 pounds.*
Martin: *We're right around that. Yeah, that's our average ... I feel a lot better.*

Everything is on track and the system is functioning properly. Curtis re-enters the control room.

Martin: *I think the problem last time was we didn't have enough power going through the voltage supplier.*

Curtis speaks to the operator and asks him to change the operating conditions on Pump #8. The operator is "in the middle of doing something and can't do that right now," so Curtis asks "do you mind if I do?" and the operator replies "that's fine." Curtis returns to the basement to reduce the flow rate on the pump.

The pressures from the basement and the computer continue to agree. The excitement in the control room is building as it becomes even clearer that the data-acquisition system is working… Curtis installs the pressure monitor and comes from the plant floor to the operations centre. [After a few minutes of testing,] he leaves [to make additional modifications on the plant floor]. The phone rings a little bit later. The operator answers it.

Operator: *Curtis says they're at 56.*
Martin: *We're at 59–60. We've got a lot of variance. It's running between 57 and 66.*
Operator: *Yeah, they're still about 60.*
Martin: *Yeah, there's a lot of variance. Look they really cranked it up. Ah, I'm so proud of this. They just turned it down and it went down. They cranked it up. (He's giving the play-by-play description of what the screen readout is indicating.)*
Nate: *It's going down now.*
Martin: *Are we doing five-minute values? Write that down. We're now at 80. Do we need to average more values?*

Nate and Martin are working together seamlessly, Martin watching the computer screen and Nate keeping an eye on the control-panel flow-rate indicators.

Curtis: *(Comes back to the control room.) It really took a big jump.*
Jessica: *Yeah, it went to 120.*
Curtis: *Yeah, then I backed it off.*
Martin: *Well, these two are 10 pounds low and that one's 10 pounds high. [He's comparing the manual readings to those from the computer].*
Russell: *Pump 8's reading right?*
Curtis: *Yeah, that's the one I just put on…*
Marianne: *Watch it jump around on the screen over here when it changes!*
Curtis: *I think if you come up here one or two at a time, you could show the operators how you use the system. It'd be valuable to us to make a decision on how we're going to end up leaving this. I think if the operators have a sense of the system, they could help us decide what to do….*
Marianne: *Oh, yeah. It levelled off. He [Curtis] walked over there and he said 56. But when he was saying 56, I was reading 60 over here.*
Martin: *I'm much happier.*

Curtis: *Yeah and that slug keeps the pressure up, it's a hysteresis [a delayed reaction that is working its way through the system]…. Up here you're dampening the transducer signal and down there we dampen the mechanical signal.* (Pointing out differences between making pressure measurements.)…

Throughout, the students worked seamlessly with Curtis.

During teamwork in the plant, Curtis seemed a member of the team, one with more authority and context-specific knowledge in the plant setting, and one with more engineering experience. His experience became evident in the use of somewhat more technical language, something only Marianne and Martin matched (though not on this occasion). His authority is demonstrated via directly communicating with the plant operator, which meant interrupting the operator's work in a complex power-generation setting (work students cannot disrupt). But, notice that in the control room the plant operator had the most authority, as indicated by Curtis' asking the operator for permission to alter plant operating conditions. Late in their two-semester design course, the Sludge Team was embedded in the sludge-disposal operations of the plant, some were becoming plant experts, and the system they designed held potential to become part of the plant's operation.

ENACTED PRACTICES

At the plant visit described, some students practiced subtleties of engineering sociotechnical interactions (Martin, Marianne, Nate), while others were invisible in the log of activity (Russell, Jessica). Martin, Marianne, and to a lesser extent Nate were in the thick of things and using content they learned in conventional classes to make sense of the real-world context of their project installed in this plant. As had been the case on many earlier plant visits, Russell and Jessica could not interpret what occurred in engineering terms. This split divided Social Over-Achiever (Greek) engineers (Russell and Jessica), from Nerd engineers (Martin and Marianne) and an Academic Over-Achiever engineer with aspirations to become more like Martin (Nate). In a fashion typical of his teamwork practices, Nate stayed close to Martin, by agreeing to read the pressure outputs from the plant control panel, and was thus ideally situated to soak up Martin's understandings about the pressure-monitoring computer hardware and software. Thus, Sludge Team student engineers ranged in their capabilities to understand equipment and its suitability in this context: Russell and Jessica had little, Nate was learning some, and Martin and Marianne proved quite adept.

The vignette of the pressure-transducer installation and systems testing, drawn from an activity analysis of their team's data set, illustrates that student engineers' capabilities demonstrated or enacted different engineering practices connected to different types of engineer identities. Marianne and Martin practiced engineering during their design project work by finding, understanding, and deploying generalizable academic-science understandings in context-specific ways. This involved using social interactions to seek salient information, share insights, develop strategies for proceeding, communicate what they had found, delineate constraints, weigh alternatives, and otherwise hone approaches to the team's project that would fit what they knew about engineering from their conventional coursework into the technical and nontechnical world of their project. For instance, Martin's last-minute decision to boost the voltage to ensure a robust signal came directly from his electrical engineering academic understandings. But knowing that this situation was the right time and place to use this knowledge came from his having throughout his undergraduate studies aligned with an approach to engineering practice. This gave less prominence to grades, class rank, and status and more prominence to being able to use what he learned in classrooms to figure things out in the real world, that is, design engineering. Martin's teammates watched his engineering practices during design teamwork and concluded that he fit among Nerds, as happened for Greeks and Over-Achievers with their two forms of academic-science engineering practice. Students' actions simultaneously demonstrated forms of engineering practices *and* who they were as student engineers.

As implemented at PES, design teamwork provided only limited situated learning opportunities for student engineers, opportunities to become an engineer (or develop old-timer practices) in the presence of an old-timer engineer as anticipated by situated learning theory in a community of practice (Lave & Wenger, 1991). Here, community novices – students – lacked frequently recurring interactions with Curtis in his workplace engineering community. Plus, Curtis' being an 'actual' engineer could not be placed within PES cultural knowledge about how to be engineers or do engineering. In fact, rather than the unitary end-point posited by Lave and Wenger, in PES culture *multiple* enculturated, sociotechnical identities existed – Nerds and Over-Achievers – each aligned with different campus engineering practices, and these were hierarchically arrayed. Learning engineering at PES coproduced identities and practices, campus institutionalized routines framed the co-productions of engineering identities and engineering practices, which blunted the impact a client engineer, like Curtis, might have on students' being inducted into industry-like engineering practices.

PES ENGINEERING CURRICULA FRAMED IDENTITY AND PRACTICE PRODUCTIONS

Institutionalized preferences for academic-science engineering (and Over-Achievers) ahead of design engineering (and Nerds) seemed to make the sort of engineer that Curtis demonstrated, the heterogeneous sort recognized in workplaces, fade into the background or disappear in students' campus lives, especially to disappear from the enculturated understandings – intentional and unintentional curricula – being learned. Ultimately, on-campus preferences continuously challenged students who considered the Nerd form of engineer or its affiliated design-engineering expertise – both modeled by Curtis – desirable in the campus milieu. Thus, student engineers' engineer identity and engineering practice understandings, those being produced and reproduced through meaning-making activities on campus, did not come from nowhere, but represented cultural knowledge framed by curricular structures, pedagogical practices (e.g., valuing academic-science-like items for assessing student progress and standing), and faculty/student interactional routines wherein some gained power to make their version of normality stick. Campus culture – continuously produced, mediated meaning-making during everyday life on campus – inhibited student engineers' thinking of themselves as 'actual' engineers. In the final analysis, campus culture won out over industry versions.

As institutionalized, campus proclivities aligned with conventional courses, and trumped design. In the larger campus milieu, conventional courses determined students' futures, which were underpinned by *academic-science* criteria for success. This promoted one sort of engineering practice, an academic-science form, ahead of others. Over-Achiever students placed their individual on-campus success ahead of design teamwork commitments and quickly learned to dodge their share of design work or perform only a minimal amount. Here, in great measure, students became themselves as engineers in a milieu where campus controlled students' everyday lives and – to many students who rose to prominence and who aligned with engineer identity terms affiliated with being Over-Achievers – design seemed a particularly time-intensive add-on to the real curriculum, not an integral part of how one went about doing engineering. Yet, in spite of this imbalance between the campus culture's favouring conventional (academic-science) engineering practices even in design courses, Nerd members of student teams took the campus design rhetoric very seriously, because they thought that this was what 'actual' engineers did: design-engineering practice.

Campus curricula, teaching practices, and other corporate ways of life, called the tune to which engineer identities and engineering practices danced, and this dance included very little influence from design experiences. Aligning with design practices meant short-changing those activities that made campus stars. Thus, it came as little surprise that in this milieu the identity terrain emerged as it had, or that student engineers who affiliated in different places in the terrain performed themselves as engineers in ways that embodied associated, but different, engineering practices. Ultimately, in spite of all the good that came of adding design courses to the campus curriculum, campus preferences for some sorts of engineers ahead of others, and for one form of engineering practice ahead of another, as well as deep-seated masculinization of engineering at PES, contributed to the sociocultural production of inequities on campus.

CONCLUSION: ENGINEER IDENTITIES AS ENACTED ENGINEERING PRACTICES AS EXHIBITING ENGINEER IDENTITIES

Instead of the word 'engineer' inferring a common, stable, shared, practitioner identity (such as seen in Lave and Wenger's African tailors, 1991), at PES engineer identities exhibited rich variation. PES student engineers revealed a world in flux that tended toward staying the same while learning to become engineers and to do engineering mediated by local circumstances. PES engineer identities linked the personal realm with collective understandings about engineering practices produced in this community of practice:

> *[I]dentities are improvised – in the flow of activity within specific social situations* – from the cultural resources at hand. *Thus persons and, to a lesser extent, groups are caught in the tensions between past histories that have settled in them and the present discourses and images that attract them or somehow impinge on them.* (Holland et al., 1998:4 – emphasis added)

PES engineer identities proved the loci for learning to belong and for learning to practice what counted as engineering on campus. But, students learned to belong to an *engineering education* community of practice, not an *engineering* community of practice (as envisioned by the design-reform rhetoric). Campus historical practices proved an influential juggernaut for the design courses to counter. At PES belonging entailed a process mediated by ideologies of privilege, which countered implications that belonging involved merely meeting membership criteria (McIlwee & Robinson, 1990; Seymour & Hewitt, 1997). Here, belonging required being *recognized* through campus (and societal) sociocultural structures, emphasizing how campus culture reached via student engineers into cultural processes that shaped, indeed generated, belonging.

Engineer identity at PES reached beyond an individual's presentation of self, beyond demonstrations of engineering expertise, and ultimately depended on tacit knowledge encompassed in engineer identity terms through which PES insiders recognized who belonged. In the final analysis, not all capable student engineers emerged as belonging, and the lack of a cultural language (engineer terms) for *recognizing* some students as engineers made some students (e.g., women who practiced design engineering, gays and lesbians) invisible as engineers (which signalled *not belonging*). In use, the terms made some seem less than they were (Martin's hiding his feminine aspects), and others seem to be more (student stars giving the impression of being more knowledgeable than they were). Thus, student engineers learned to embody past and current ways of campus life, cultural knowledge at odds with empirical evidence (Martin, for instance, who *re-produced* the campus world via his statements about women not fitting among Nerds), illustrating the power of cultural knowledge to *make* a local world.

At PES, learning to be engineers and to do engineering meant taking up an *intended* scientific and technical curriculum (and for design-engineering practitioners a sociotechnical curriculum), as well as learning a complex *unintended* curriculum that encompassed cultural knowledge specific to this campus and to life in the US. Learning these bodies of tacit knowledge entailed learning, but not noticing, vestigial traces of past practices germane to engineering (Oldenziel, 1999). Productions of campus culture, and of belonging, arose in – and made – space and time. Here, becoming an engineer – having an engineering education and doing engineering – meant making the way of life at PES *seem* normal:

> *'[C]ommunities' aren't just situated in space and time, they are ways of* producing and organizing *space and time and setting up patterns of movement across space-time: they are networks of power. People don't simply move into these networks in an apprenticeship mode, they are defined, enrolled and mobilized along particular trajectories that move them across places in the network and allow them to move other parts of the world into that network.* (Nespor, 1994:9 – his emphasis)

My research illustrates that, at PES and in communities like Nespor describes, it seems reasonable to deduce that some people are moved *out* of trajectories that might otherwise move them into such networks, and here identity terms served as the linguistic denotation (cultural knowledge) to signify belonging, or not. To say that engineer identities enacted engineering practices (or concurrently that engineering practices exhibited engineer identities) implies the intertwining of engineer identities and engineering capabilities, as well as of gender and power, which taken together encompassed the understandings needed to get around in campus culture.

While engineering campuses in the US vary somewhat, Public Engineering School represented a typical-campus case and the design courses where fieldwork was situated included students from all engineering sub-disciplines, increasing the likelihood that results from PES might apply elsewhere. What seems to be at the heart of the findings concerns the cyclical nature of the culture-production processes that moved PES through time and produced very little real change. Situated learning proved central to becoming engineers on campus, but the campus ensured an educational, not an industry-like, community of practice, though glimmers of opportunity in design coursework existed. Learning to be an engineer entailed not only developing engineer identities, but also learning engineering practices affiliated with different identities, just as deploying engineering practices (acting in particular ways on campus) signalled (were interpreted as) different engineer identities. Campus culture framed these enculturated identities-practices productions, just as such productions contributed to re-producing campus culture and its inequities. And, though well-meaning faculty advocated shifting the engineering curriculum toward more industry-like practices, appending design courses alongside a long-standing conventional curriculum (one little changed from course catalogues of 25 years earlier) failed to decentre historical practices.

NOTES

1 Social settings imply (here) an often transient, or short-lived, place where individuals interact, a place where historical persistence proves less salient.

2 Note the singular and plural forms of the words identity/identities and practice/practices. In the singular, I infer a large encompassing *concept* that includes varying, particular identities or practices. In the plural, I infer the particulars in play. I am here writing against a notion that there is a single

sort of, or target, person that can be captured by the word "engineer," or a single target practice that can be captured by the word "engineering." To denote such a target, I use the term "hegemonic" engineer or "hegemonic" engineering, the one that holds sway in a particular time and place. Such a target engineer or engineering is thus a power-infused version of possibilities.

[3] Survey results provided a check on the extent to which this campus matched earlier sex-comparative results about the nature of engineering (McIlwee & Robinson, 1992, whose fieldwork occurred in the 1980s). In the main, PES sex-comparative results mirrored those from a decade earlier.

[4] See Tonso (2006) for descriptions of individual identity terms.

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6. CDIO ENACTED

Tracing the Multiplicity of an Initiative in Engineering Education

INTRODUCTION

At many higher education institutions offering engineering programs worldwide, the CDIO initiative has been introduced and implemented to ensure that students acquire the skills needed by the engineering industry and to connect engineering education to the practices of engineering workplaces. The letters stand for Conceive, Design, Implement, and Operate and the initiative is structured according to a logic covering the whole chain of processes involved in developing and maintaining products at the workplaces of engineers (Crawley, Malmqvist, Östlund, & Brodeur, 2007). The idea is to demonstrate the phases involved in professional work and the variety of skills needed for engineering at large. The initiative involves guidelines on how the students should organize their group work and on the framework of curricular planning and outcome assessment.[1] The intention is that all parts of engineering education be structured and assessed through this initiative.

The developers and users of the initiative argue that by connecting engineering education to the working life of engineers and ensuring that students acquire specific skills, CDIO will make the students more 'employable' for the companies (Clark & Andrews, 2011). In 'Reforming engineering education – the CDIO initiative', Crawley et al. explain that CDIO is born out of a rigorous engineering process following the phases of CDIO where the problems have been identified. The initiative has been designed to be implemented and operated in engineering programs in 111 countries[2] (Crawley et al., 2007:3). In the authors' opinion, then, the logic behind CDIO is also the logic that has been used to develop the initiative as a structured framework to be implemented by the universities. However, CDIO involves several logics concerning pedagogical considerations, following the different phases that will be explained further below.

Following the argument about the structured logic it becomes important to explore what happens to a structured and structuring initiative such as CDIO when it is applied to the messy and unpredictable lives of people and materials. A great amount of work has been done on the reasons for developing and implementing CDIO and how the initiative structures the education of engineers (see for instance

U. Jørgensen & S. Brodersen (Eds.), Engineering Professionalism, 105–123.
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Edström & Kolmos, 2014; Bankel, Berggren, Blom, Crawley, Wiklund, & Östlund, 2003; Gaidi, 2003). But not much research has been done by empirically exploring the initiative in the lives at the universities. Therefore, this chapter will take a closer look at how the concept of CDIO becomes enacted (Mol, 2002) in the daily lives of students and instructors at two engineering universities in Denmark, Technical University of Denmark (DTU) and Aarhus University School of Engineering (ASE).

Given how structured the initiative of CDIO looks on paper, it becomes interesting and important to analyze how the initiative looks when it is enacted by the people for whom it has been developed. Through those enactments it becomes possible to analyze how workplace and education are connected or entangled in the lives at the universities. The intention with the chapter is not to evaluate whether or not the workplace and education become connected through the implementation of CDIO, but rather to explore empirically how CDIO is enacted among students and instructors in classes and group work and how workplace and education are entangled in these enactments. By following students in their classes and group work and asking questions in different contexts, I have been introduced to CDIO in various ways. By looking into these enactments of CDIO I will explore how CDIO is given meaning in different situations.

INTRODUCING CDIO

CDIO is an educational initiative and a framework for curriculum planning and outcome based assessment,[3] as well as a global network for engineering education. It was developed by the four universities Massachusetts Institute of Technology (MIT) in the USA and Chalmers Institute of Technology, Linköbing Institute of Technology, and the Royal Institute of Technology in Sweden (Crawley et al., 2007).

The incentive to develop CDIO derived from tensions in the 1980s and 1990s between engineering education and the industry. The industry critiqued the institutions providing engineering programs for teaching academic knowledge only, without equipping the students with the tools they needed to work on a daily basis as engineers at the companies (Gaidi, 2003; Crawley et al., 2007). Some of the major companies in the USA compiled a list of the skills they wanted their future employees to possess (Crawley et al., 2007; Gaidi, 2003:432). In 2000, the four above-mentioned universities took up the educational challenge and invented the initiative of CDIO to help the educational institutions teach these skills to their engineering students. The initiative was based on the demands from the North American context, but was made to be adapted to other national contexts.

CDIO now works as a network that institutions offering engineering programs can join. To become part of this network institutions have to meet at least 7 out of 12 educational standards that have been formulated under the initiative of CDIO and explain how CDIO should be implemented and what should be considered in the implementation. The standards are both pedagogical and structural phases that the students must go through, as well as standards for teaching and assessing outcomes. The standards also function as guidelines the institutions must follow to implement and evaluate the program they provide as a CDIO-structured education. Through the standards, CDIO becomes a tool to ensure that the students develop the skills needed to become employable engineers (Crawley et al., 2007), including personal, interpersonal and professional skills (Edström, Törnevik, Engström, & Wiklund, 2009). The standards also involve assessing the students' products and thereby evaluating their progress and continual development (Bankel et al., 2003). The standards show how the initiative touches upon and structures the majority of the programs and how the idea of workplace logic is supposed to imbue all aspects of the engineering programs. The standards cover the kinds of knowledge the students need to acquire, how they should acquire this knowledge, and how they will be assessed. Later in the article it will be shown how these standards influence the structure of the semesters and how this in turn affects the enactments of CDIO.

Table 1. The 12 Standards Constructed with inspiration from the CDIO handbooks from both universities (ASE, 2012 & DTU, 2013)

1	The educational philosophy and the principles behind CDIO as context.
2	The aimed knowledge, skills and the competencies consistent with CDIO syllabus.
3	Principles of developing the syllabus and the integration of curriculum.
4	Design-build project in the first semester – introduction to engineering.
5	Design-build experiences throughout different curricula.
6	Develop CDIO workspaces for experiments and hands-on learning.
7	Principles for integrated learning experiments, including interpersonal skills.
8	Active learning – teaching and learning through active methods.
9	Enhancement of educators' CDIO skills.
10	Enhancement of educators' teaching skills.
11	Assessment of the students' requirement of the CDIO skills.
12	Evaluation of the CDIO program in general at the education.

Another element of the initiative is the idea behind the four letters C – D – I – O, which symbolize the four phases of most engineering projects in the industry. The argument is that contemporary engineers are involved in all phases of developing a project or product and therefore the students need to integrate the phases of their work in the educational setting. The first phase, Conceive, involves conceiving ideas, defining customer needs, and making business plans for the project. The second phase, Design, entails the creation of the design of the product, making drawings, and doing calculations and algorithms. The third phase, Implement, involves transforming the design into a product, including all the hardware elements: the product is built in real life. The final phase, Operate, involves delivering the product and ensuring that the product operates as intended by addressing any elements not working (Crawley et al., 2007:8–9). Students must go through these four phases when they do their mandatory projects in groups. Group work is part of the idea, since interpersonal and communication skills are part of what they need to learn. Following all four phases is the ideal of using the workplace logic in the educational context. However, running production and maintenance processes are not easily included in all processes in the engineering programs, for instance, in design programs, and therefore the educational institutions face some challenges in implementing the four phases in all engineering disciplines (Jørgensen, Brodersen, Lindegaard, & Boelskifte, 2011). This means that certain challenges emerge when implementing workplace logic in an educational setting, and this will be reflected on in the discussion.

Participation in the CDIO initiative does not require certification; educational institutions can participate if they implement 7 of the 12 standards, as mentioned above. In the description of CDIO it becomes explicit that since education takes place in different contexts, the implementation of the standards and of CDIO will vary from institution to institution. The two educational institutions in this chapter have quite similar reasons for implementing CDIO. In their own handbooks on CDIO, they argue for its relevance.

At DTU, CDIO has been implemented since 2008; in DTU's handbook it is argued that CDIO ensures that the students acquire the skills they need on graduation (DTU, 2013). It is also stated in the handbook that by following the CDIO standards the different programs are able to document a coherence and progression in the educational process, including the practicum the students do at an engineering company. Furthermore, implementing CDIO ensures that the university produces engineers who can engineer. Structuring the progression of the education and producing these engineers thereby become the main arguments for implementing CDIO.

The staff I interviewed in the administration group responsible for implementing CDIO at DTU explained that the pedagogical considerations of CDIO were also very valuable. The way the students produced a product each semester in groups was to them important for creating engineers who can engineer. This also became helpful in "convincing" different instructors to become more "practically" oriented in their teaching, letting the students produce something as well as teaching them the curriculum knowledge.

At ASE, CDIO has been implemented since 2010 and their handbook states more or less the same reasons for the implementation (ASE, 2012). This handbook emphasizes that the conceive, design, implement, and operate phases correspond to the phases that are followed at the engineering companies in Denmark. Implementing the initiative is thereby a way to ensure that the students acquire the skills they need to enter the engineering profession. It seems that for both these universities CDIO supports the institutions' goal of producing students who are ready to work at engineering companies, which is consistent with the main reason for developing CDIO in the first place.

In an interview, the administration group at ASE explained to me that following the phases of the companies in the educational processes is nothing new to this university. They argued that structuring the programs in a way that resembles the way of working at the companies was something they had been doing for a while, and paying attention to the companies' needs was an inherent consideration that followed their close contact with companies in relation to planning the students' practicums. So for them CDIO is more or less a way to make explicit what they have been doing for some time. CDIO confirmed that what they already did was internationally acknowledged as rational practice in engineering education. Still, the structure of the phases and the standards for evaluating the progression of the programs are emphasized as logical because engineers like to systematize their work to reach their goals, they explained.

INTRODUCING THE EMPIRICAL MATERIAL AND RESEARCH METHODS

The present chapter is based on two examples of empirical fieldwork conducted between 2011 and 2013 at ASE and DTU.[4] Fieldwork in the context of this chapter is understood as ethnographic fieldwork consisting of qualitative methods such as participant observation and interviews. As an educational anthropologist my main concern is to create knowledge about the way people live their lives in educational practices by understanding these lives in practice (Hastrup, 2004; Vinck, 2003). When doing for instance participant observation the ethnographer follows the people (called informants during fieldwork) who are the focus of the study and positions herself together with them (Hastrup, 2004, 2013; Clifford, 1984).

During the cases of fieldwork in question I have done this by following a group of students in their daily life at the universities for a period of time. I have listened to the same lectures, participated in their group work (more or less actively), gone to coffee and lunch breaks together with them, and taken the bus to and from the university. In other words, I have tried to participate in as many activities during their day as possible. A part of doing fieldwork is also to conduct interviews with the people whose lives are in focus. The interview is a way of asking questions about the daily life that has become known to the ethnographer and to let the informants articulate their opinions. In the fieldwork used in this chapter interviews have been conducted both as semi-structured interviews planned beforehand, where I have formally sat down with the informants and recorded the conversation, but also as informal interviews, which have taken place spontaneously during the participant observation. These methods allow for an understanding of how the students experience their daily life and the challenges they meet and also how the experiences and challenges change in different contexts. When studying an educational initiative, such as CDIO, as a series of enactments, it becomes possible to understand how different rooms, situations, and contexts affect and engage in the enactments. By doing participant observation it also becomes possible to study the complexities of lives and to come up with suggestions for development based on those complexities.

The two fieldwork cases analyzed in this chapter derive, as mentioned above, from two universities in Denmark, DTU and ASE. Both fieldwork cases have been concerned with the bachelor's program in engineering, since this is where CDIO has been implemented so far. In Denmark there are two kinds of bachelor's programs in engineering. One is mainly academic; students take a three year bachelor's degree in engineering and in the most cases continue to a master's degree. In this case, the bachelor's program is considered a preparation for or a part of the master's degree. The other is a three and a half year bachelor's program that has vocational objectives as well. This bachelor's education includes a practicum semester, in which the students become integrated as interns in an engineering company. This bachelor's program can be followed by a master's degree as well, but the students are supposed to be ready for employment directly after finishing the degree.

The three and a half year bachelor's degree can be taken within many different areas of engineering.[5] At ASE I have focused mainly on students following the program in health care technology and at DTU I have only followed students in the program in building construction. Both universities have implemented CDIO within the past five to ten years, so all the bachelor's programs have in common that the students have to do a project each semester, which involves working in groups and following the phases of CDIO. To make CDIO operational both universities have, among other things, produced a matrix of the different courses included and skills developed in each program to ensure that all programs follow a progression that incorporates the 12 standards. Additionally, they have incorporated group work following the four phases in each semester.

The fieldwork at ASE lasted approximately two weeks, during which I conducted interviews with students, instructors, and administrators and participated in the classes of students in health care technology. In the interviews with the administrators and instructors I have been explicit about my focus on CDIO, but the students were not aware of the CDIO initiative and that the program was structured according to it, so I did not ask questions about CDIO in the interviews with them. In those interviews I focused on the students' projects and their ways of talking about their education and workplace in relation to each other, as well as the way they worked on their projects. The students I followed during the participant observation were in their second semester.

The fieldwork at DTU was less focused on interviews and more focused on participant observation and following the students in their different courses and group work. This fieldwork lasted approximately one month and started at the beginning of the fourth semester of the program in building construction.[6] The majority of the fieldwork consisted of participant observation; I followed a group of students every day to their classes, group work, lunch breaks, and other activities. I conducted informal interviews with the administrators who were responsible for implementing CDIO as well as the instructors of the courses the students followed. I also did a semi-structured group interview with the students. The empirical material from this fieldwork is more extensive than that of the first one, and therefore I have more examples of how CDIO becomes enacted in the daily lives. For that reason DTU is my main focus in the analysis, but the examples from ASE will be used to emphasize some of the enactments emerging from the analysis of DTU.

ENACTMENTS IN MESSY LIVES

A few theoretical concepts are needed to analyze how the CDIO initiative is being enacted in the daily life at the universities. At the center of this analytical frame is the concept of enactment. Because the analysis focuses on how CDIO can be understood in the lives of students and educators, and not as it is defined by the developers of the concept, it needs to be viewed as enacted. My inspiration to use the concept of enactment derives from philosopher and anthropologist Annemarie Mol, and her theory of what she calls praxiography (Mol, 2002:31–33, 55). Enactment is a concept used by several different theorists.[7] My version of enactment derives from a feminist tradition inspired through Mol by Judith Butler (for example 1990), Karen Barad (2007), and Dorte Marie Søndergaard (2012). Butler uses the term much in line with Mol, by arguing that reality (and in particular, gender) is enacted (1990). In the same line of thought Søndergaard uses enactment as a concept to explain how everything comes into being in relation to (and in intra-actions with) something else (Søndergaard, 2012; see also Barad, 2007). I build on those definitions of enactment and move on with Mol, since her theory focuses specifically on multiple realties, which is productive in the analysis of CDIO as multiple.

Enactment means that something becomes something in the context where it happens (Mol, 2002:32–33). Praxiography entails focusing on practices rather than principles, which means that concepts should be explored according to how they are enacted and not how they are defined. This involves the method of ethnography since only by observing the practices can we study the enactments in those practices (Mol, 2002:28–32). What is being enacted does not only depend on people; things and contexts are equally part of the enactments. Mol's own research interests are bodies and diseases. She analyzes a disease and argues that the same disease is being enacted differently in different contexts. For instance, doctors at a hospital might talk differently about liver disease than doctors at a rehabilitation center, and both ways are part of the multiple ways of understanding liver disease. Something is only something in the act and in the practice in which it is enacted (Mol, 2002:32–33). The term enactment, then, allows me to analyze CDIO as it emerges in the different contexts at the universities. How CDIO is defined by the developers of the initiative is only one of the ways CDIO is enacted, and the way the students, instructors, and materials enact the initiative must be regarded as what the initiative also consists of. This prompts an understanding of how the initiative changes depending on who (and what) is enacting. The analysis will explore these enactments and reveal more sides of CDIO than what is revealed by the developers of the initiative. There is a difference between studying diseases and studying a concept such as CDIO, though. Mol argues that a disease can be enacted as more than one but less than many

(Mol, 2002:55). This might not be the case when studying a concept, since there seem to be many ways of enacting CDIO. What frames the enactments is the field of engineering. The praxiographic shift towards studying something as it becomes enacted in practice as opposed to how it is defined is a key point in the context of this chapter. Mol's idea of focusing on practices over principles is what guides the analysis of the many ways CDIO become enacted.

To further develop the point of revealing more sides of CDIO I use the term messy lives as introduced by sociologist John Law (2004). CDIO involves definitions, guidelines, and standards for the universities to follow. On paper it looks very orderly and structured. Lives, on the other hand, are not ordered and structured. Lives are messy and complex and by starting with that premise I am able to explore the multiple ways CDIO become enacted and thereby show how the initiative assumes different forms when released from the paper into the lives at the universities. This approach helps me focus in the analysis on the relationship between the structuredness of CDIO and the multiplicity of CDIO as it becomes enacted at the universities.

The goal of CDIO is to make better connections between future workplaces and engineering education. By studying CDIO as enacted in multiple ways the connection between working life and education also becomes multiple. In relation to this goal it becomes interesting to explore how this connection is made when CDIO is enacted in multiple ways. By doing so, the chapter enters into a discussion about theory and practice in engineering education. Inspired by this discussion the chapter has as a premise that theory and practice are not separable entities, with theory happening at the educational sites and practice happening at the workplaces (Kamstrup, 2015). Theory and practice happen in all of these places as entangled phenomena (Barad, 2007), which leads me to explore how educational institutions and workplaces are entangled in the enactments of CDIO.

TRACING ENACTMENTS OF CDIO

The next sections will delve into different empirical cases, all of which enact CDIO in different ways. Throughout the fieldwork I tried to figure out what CDIO was beyond what I had learned about the initiative from my reading. A part of the fieldwork consisted of confusion about the various ways CDIO was described, used, and talked about and I found myself trying to trace all these different enactments of the same initiative. This confusion is also part of the inspiration for this chapter. The analysis of the enactments reveals a picture of the multiplicity of CDIO that can be discussed in relation to the structured intentions of the initiative and the entanglements of workplace and education. I treat the following empirical field notes and interviews as cases (inspired by Mol & Law, 2002), which means that each case should be treated in its own right, and I do not wish to find a hidden truth about CDIO by analyzing them. Rather, the cases will show enactments of CDIO and by drawing out similarities and contradictions in these enactments from each case I will be able to explore the multiplicity of CDIO in the lives at the universities.

CDIO as Something That Structures a Semester

Before starting the fieldwork at DTU, the administration explained to me that the fourth semester was the best one to follow if I wanted to study CDIO. One of the people responsible for implementing CDIO explained that all the courses were connected and that the students worked with the same project in three of the four different courses. This also meant that the students had to work with all the Conceive, Design, Implement, and Operate steps and that some of the 12 standards – for instance integration of curriculum and activity based learning – were applied. This was confirmed by an instructor in technical building services, Philip,[8] whom I met in the first course I followed. He explained to me that this semester was tough because the courses demanded a lot of the students, and because they had an extensive project to plan between three of the four different courses they were taking. How exactly this worked for the students through the three courses never became fully clear to me. They worked in groups, but since not all students took all of the courses (some retook them because they had failed them the semester before), they had to have different groups in each course. Philip was very persistent in explaining to the students in the first lecture that this was a semester where they used the CDIO principles, but when I asked the students about this, they talked about the confusion of the different groups and were not able to describe the relation between the different courses. Philip also kept reminding the groups, throughout several lectures, that they had to follow a specific timeline, and since they were working according to the CDIO principles, they had to select a leader of the group and a person who was in charge of all the documents they were using. In other words, CDIO was articulated in many different ways in relation to this semester and as such present in the minds of at least the instructors of the courses. Listening to the students' discussions about planning their group work, however, did not reveal any thoughts of CDIO and the connection between the three courses. After a class where Philip had emphasized the CDIO phases, I ask Mitch, one of the students, about how CDIO and all of the courses are connected

Mitch: *It's really only two courses that are part of the project we are going to make. We have established the groups now, but for instance in soil mechanics, we are only allowed to be three students in a group.*

Anne K: *And is that project a CDIO project then?*

Mitch: *Well, they are super cute about their CDIO. It's something that we had a course about our very first semester, but we don't think about it when we do our projects. It's the way the projects should be structured, but they don't really use it.*

The quotes from Mitch indicate that how the semester is structured and the courses are connected can be understood differently depending on who is asked. When talking to the instructors and administrators I got the impression that the semester was tightly structured by the CDIO initiative and by the project that connected the courses. By the instructors and administrators, CDIO becomes enacted as something that meaningfully structures a semester for the students, both by connecting the different courses and also by giving the students guidelines to structure their projects. Philip emphasizes even more workplace practices, such as having a leader in the group and a person responsible for keeping all their papers and documents organized. Inspired by the CDIO initiative, he encourages the students to adopt a workplace logic in their group work. By Mitch, CDIO becomes enacted as something the instructors are cute about, but it does not help him make sense of the semester he is taking. All the links to CDIO that Philip makes are not connected to CDIO by Mitch; rather, he thinks of the initiative as something they learned about during their very first semester, and something the instructors talk a lot about, but it does not influence the way the students work on their projects. Whether or not their way of working is in fact influenced by the CDIO initiative is not to be judged here; the point is that in this specific case CDIO becomes enacted on the one hand, as a structuring element and on the other, as something rather silly that is not used.

CDIO as Something the Instructor Can Bring to Class

Philip and the administrators enacted CDIO as a structuring initiative that organized the semester and courses and also entailed a specific way of conducting group work. He articulated CDIO and the included structure both to me and during class when explaining the structure of the semester to the students. Another instructor, Oscar, who taught soil mechanics, also specifically articulated CDIO in the classroom, only as something quite different. From my fieldnotes:

This is the first lecture of the course called soil mechanics. About 50 students are sitting at the desks in the classroom waiting for the lecture to start. I wait along with them. The instructor, Oscar, enters the room and goes to the front of the classroom. Since I have not met him before, I approach him to introduce myself. I tell him who I am and he recalls that I am interested in CDIO, which I confirm. He says: "Now, I've forgotten my CDIO today. I'll have to fix that in the break." He starts addressing the class and I return to my seat a little confused about the remark about the forgotten CDIO.

For an hour or so Oscar lectures about different kinds of soil and how the soil influences the construction of buildings. He shows pictures of buildings in different environments and talks about how the soil has been considered in the construction of those buildings. After an hour there is a break and Oscar leaves the classroom only to return five minutes later carrying a box. The students turn their attention toward him again.

Oscar: *So today we have an anthropologist sitting in the classroom, so now it is really going to be CDIO, because now we have to touch the materials.*

The box, it turns out, contains several bags of different kinds of soil. The students are to divide themselves into groups and pick up five bags of soil.

The students pick up the soil and start to investigate each of the bags, and I join one of the groups. The students have remarks about each of the bags. "It smells like sand" or "it smells like dirt". Some of them are a little hesitant to touch the wet soil. They look in the books and write down how they classify each type. Most of them are classified as sand, silt, or humus. Some start to play with the soil, making little balls, but after a while everyone has washed their hands and they all return to their seats.

Oscar then talks about the group work. He says that even though we call all of the types soil, they are very different. He has the answers to what I thought were more subjective things such as the color and smell of the soils. He gives the correct answers to each type of soil, and it turns out that the group I followed was wrong about a few of them. They do not ask any questions though, and he then starts lecturing about something else.

The course in soil mechanics was supposedly also a part of the three courses that were connected in the project the students had to work on throughout the semester. As opposed to Philip, Oscar did not talk much about the connection to the other courses while I was there. He was more focused on helping the students work on the assignments they had for that specific course. In this context CDIO becomes enacted as something you can bring to class. The soil samples and the students' opportunity to touch, smell, and taste them are all factors that enact CDIO in this case. Apparently, bringing something from outside – both from outside the classroom, but also more literally, from the ground somewhere outside – justifies the classification of CDIO. This might be because it relates to one of the 12 standards concerning hands-on learning. Oscar does not relate to the phases of CDIO, but rather to an entanglement of outside and inside that becomes apparent through the enactment of CDIO. Or more specifically, inside and outside becomes entangled when he brings soil into the classroom, and this is defined by him as CDIO. It seems that Oscar's approach to using CDIO in his classes is introducing the students to materials related to the workplaces of construction engineering.

During an interview with some of the students who followed the above lecture on soil, I ask a couple of questions about the group work that Oscar introduced as CDIO.

Martin: *Some of those things are also a pedagogical initiative. The instructor, I mean, he wants us as students to touch that soil. And of course we can feel the difference between the different things [soils], I mean people like us who do not have much experience… Well of course I know that clay is tough and sand crumbles, but there are so many* *other types, so it is pretty entertaining pedagogically speaking and we do get to touch the different soils. But besides that, there is not that much to it, is there?*

Bridget: It irritated me a little because none of the groups really came up with the right solution, because we had not worked enough with the different types of soils. But if I am making calculations of soils, then I look back and think, well, that was what I held in my hands. So in that way it is okay.

What Oscar introduces as CDIO, the students here interpret as a pedagogical initiative. They all agree that touching the soil adds a different kind of knowledge to the course than the calculations they usually work on. The physicality of bringing something from the outside into the situation where they are learning and making calculations is not a very impressive pedagogical approach for the students, whereas for the instructor, this practice can be considered CDIO.

CDIO as a Course

Thus CDIO can be enacted as the practice of bringing soil into the classroom. Even though the students participate in this practice they might not themselves acknowledge that CDIO is a part of what they are doing. In an interview I decided to ask the students more directly about their knowledge of CDIO, because in the classes it was mostly the instructors who brought it up.

The first time I mention CDIO in the interview they start to talk about the initiative as a course they took in their first semester, which is what standard 4 involves (see table 1):

Anne K: Did that course involve you coming up with your own project?

Bridget: We had to design a house, so I guess it did.

Martin: But it was quite predefined.

Bridget: A lot of different suggestions came up though.

Sebastian: It was semi-predefined.

Martin: A part of the course involved us having to construct a house in 1:20, but the assignment contained predefined requirements of the properties of the house and its measurements, so it was pretty predefined.

Sebastian: And so was the report that we had to write about the process.

[…]

Mitch: Well, in the end our grade only concerned the report and not the house that we constructed. We constructed a crappy house, but we wrote a good report and ended up getting an A+. But I mean, Sebastian's house… It had a terrace and all!

Martin: That was a really nice house. I guess your background as a carpenter really came to the fore, Sebastian.

Anne K: *And you didn't get points for that?*
Sebastian: *Oh yes, we also got an A+. But only because two of us in the group really made an effort with the report.*

So CDIO here is enacted as a course that the students took in which they had to design and build a house. They quickly start debating whether or not the assignment of constructing a house was predefined or not, leading thoughts to the Conceive part of CDIO (which has also been discussed by Hansen & Jørgensen, 2011). It appears that in this course they followed the different phases of CDIO in building the house (with more or less freedom in the conceiving phase), and it is also the first time the students have been introduced to the initiative. So when asked, this is what they immediately think of. The house – which was the product of their group work – and the report, are also participating in the enactment of CDIO in this case. It seems to puzzle the students a bit that their grades were based on the written report and not on the house they had constructed. This implies a special kind of entanglement between imagined workplace and education, where the house represents what the students imagine that they have to construct in their future practice as engineers, and the report is where they show that they know the theory behind the construction of the house and can reflect upon their mistakes. Sebastian, who worked as a carpenter prior to his enrollment as an engineering student, does not seem to get credit for his abilities to construct a functional and nice-looking house. The focus is removed from the product to the written calculations and reflections the students have made after constructing the house. Maybe because the course was introduced as a CDIO course that is supposed to connect the workplace to the education, the role of the house seems, to the students, to be underestimated by the instructors. The phases of CDIO seem to be overruled by the practices of assessment and exam requirements. The house represents a tangible product of the engineering workplace practice, but the calculations and reflections on the constructions are no less part of this practice; they are just less tangible.

CDIO as a Concept That Structures Their Projects

Further on in the same interview I ask more specifically what CDIO means, and by asking that question CDIO becomes enacted differently again:

Anne K: *So now we talked about CDIO as the course you had, but how would you define the concept for me?*
Sebastian: *I can do that. Conceive, design, implement, operate! But then again, I am a TA*[9] *(they laugh).*
Bridget: *A lot of it is about, or at least that was my impression when we learned about it during the first semester, that the discipline construction of buildings is just like CDIO, but it's more how the discipline is structured. We use the concept a lot.*
Martin: *Whether we know it or not, it doesn't matter.*

Sebastian: *We use it unconsciously.*
Bridget: *It's about following natural steps…*
Sebastian: *Well, you have this idea phase, where you are told to construct something and then you brainstorm and come up with a real idea. Then you start making calculations of the construction, and when you are done with that you go out somewhere and implement for instance the ventilation system that you have made calculations of. You build it and in the operate phase you start making measurements to see where you have done it right or whether you have to change something.*
Anne K: *And you do that in your projects?*
Bridget: *I think maybe it's something we would have done anyway. It's a natural process that does not necessarily need to be called CDIO. We would still have used the same approach because it is logical.*

The students know what the letters in CDIO stand for and they know how the phases are connected and how it is supposed to be a way to work as an engineer. The joke about Sebastian knowing this because he is a TA indicates that CDIO is considered to be something that instructors and not students should know about. Even so the other students have reflections on the initiative and CDIO almost becomes enacted as unnecessary. They argue that with or without the initiative they would still be working the same way because it is logical and natural for engineers to structure their work that way.

At ASE, the administrators and instructors described CDIO in interviews as old wine in new bottles. They argued that CDIO represents a way of working that has been done at the university for a while, because it is a logical way for engineers to work. The students I interviewed at that university had not been informed about CDIO and were not familiar with the initiative. But when explaining how they worked with their projects they articulated the phases of CDIO as a natural way for them to work. In these cases CDIO becomes enacted as a logical way for engineers to work, both as something the universities have been doing for a while and also a recognizable way for the students to learn about engineering. Bridget describes CDIO as something that is almost inherent in the discipline construction of buildings, which entangles the imagined workplace with the way of doing projects at the university.

ENTANGLEMENT OF THE FUTURE WORKPLACE AND EDUCATION

In these cases I have shown that the enactments of CDIO emerge in multiple ways. When studying CDIO in practice the initiative becomes manifold as a tool to structure the courses, semester, and group work for the students, only the students in this context do not see CDIO as doing so. In a classroom CDIO becomes enacted as something the instructor can bring to class by bringing soil samples into the lecture for the students to touch. The students in this case interpret this as a pedagogical initiative, though, and do not connect the specific act to CDIO. In the interview the students enact CDIO as a course that involves constructing a house and writing a report about it, but also as a natural way for engineers to structure their work. The cases thus show how CDIO becomes enacted in multiple ways. The analysis should not be understood as exhaustive in relation to exploring what CDIO looks like in the daily lives at the universities. The point is that the answer to that question would always be different depending on the context and situation within the field of engineering.

The analysis also shows that all of the enactments entail ways of entangling work place and education. What brings the different enactments of CDIO in the four cases together is the common entanglement of work place and education, which is one of the objectives of the standards of CDIO.

By looking into the different enactments it becomes possible to understand the effect of each enactment in relation to entangling the educational setting with the workplace. CDIO has many objectives (for example, structuring classes and semesters with a defined progression), but in this discussion I will focus on how the different enactments relate to the discussion of entangling future workplace with the education. The analysis shows that this is what brings the different enactments of CDIO in the four cases together.

Through the enactment concerning structuring a semester, Philip explains the structure of the semester in relation to CDIO, but this does not make the students relate the structure to workplace logic. They view the instructors as cute about CDIO and do not seem to understand the rather complex way in which the structure of their semester is supposed to relate to engineering workplace logic. In that enactment CDIO becomes procedural, and perhaps almost idealizes the workplace logic. The structure does not fit the many different groups the students are participating in, and it seems that several understandings of the structure of the semester are at play. The educational logics of group work and passing courses seem to get in the way of a clear picture of how the structure of the semester should connect the education with the future workplace. It shows that the students are not open to following the workplace logic when they joke about having a leader of the group. In other words, they do not accept the fact that the instructors are trying to make an entanglement with their future workplace; instead, they are absorbed by making sense of the semester, the group work and the requirements for passing the exam.

In the enactment of CDIO as something the instructor can bring to class, the instructor articulates the point of CDIO as touching materials from the future workplace. By literally bringing a part of a potential construction site into the classroom he physically entangles the workplace and education. Interestingly, the students think of this as a pedagogical initiative, and thereby ignore the entanglement of the workplace with the educational setting. As with the example above, they focus on the episode as something related to the educational context where they have to learn and not on the attempt to entangle future workplace and education.

In fact, in the cases brought forth in this chapter, the students only acknowledge CDIO as something constructive when they talk about the specific course they took that addressed CDIO directly. They clearly understand that the phases are supposed to resemble the workplace practice and they emphasize that this is a natural way for them to work. The phases of CDIO, and thereby the phases of engineering projects at workplaces, become a way of connecting the students' imaginaries about a future professional practice and the way they do their projects in the educational setting. Presented like this, the students think of CDIO as a natural and logical part of their education, because it prepares them to work at engineering companies. But when the assessment of these projects focuses on the written report, the students become confused about the point of bringing the phases of engineering work into the educational setting. The logic of educational assessment and the logic of the workplace work against each other in the attempt to entangle workplace and education.

The multiple enactments of CDIO, then, produce multiple entanglements of workplace and education. As the discussion shows, it is not all the attempts the instructors make to connect workplace and education that the students perceive or recognize. It also shows that it is through the specific phases of CDIO that the students recognize the entanglement of education and the future workplace. It appears to be problematic for the students to engage in the entanglement of workplace and education when they also have to worry about educational aspects such as group work and passing exams. To them the entanglement of workplace and education becomes enacted when they build a house and can relate that process to a future workplace. In the other cases, they are too absorbed by the educational elements to recognize the instructors' attempts to make the entanglement.

CONCLUCION

There is a sharp contrast between the specified standards of CDIO and the various enactments of CDIO at the universities. The analysis points to the conclusion that there is no one-to-one relationship between the standards of CDIO and the skills the students acquire during their education. The multiplication of CDIO gives rise to a challenge in evaluating a structured concept in the practices in which it is being enacted in many and not necessarily predictable ways. The administration argues that implementing CDIO is a way to make sure that the students learn what they need to learn, but that goal is difficult to evaluate when CDIO is enacted in multiple ways. This is a profound problem with an initiative that tries to structure the messiness of human life. A structured initiative needs to be evaluated on the premises that when it is implemented in messy lives, it becomes multiple. And the students' acquirement of skills might need to be assessed on the same premises.

It becomes a simplification of the messy lives and enactments of CDIO in that context to evaluate the initiative as something written as standards. CDIO becomes enacted in multiple and at times contradicting ways. From this point it follows that ensuring the acquisition of skills by implementing defined standards is not necessarily possible. The analysis shows that CDIO does entangle workplace and education in different ways, but in some of the enactments the instructors' attempt to make this connection is not perceived or recognized by the students. Hence, the enactments of CDIO show that students and instructors have different agendas in some of the classes where the instructors try to connect the workplace and education using CDIO while the students are trying to make sense of their education and focus on that, rather than their future workplace. Ironically, when the students recognize this entanglement in their project concerned with building a house, it seems that the instructors obscure this entanglement by only assessing the written report and not the constructed house. This argument points to the conclusion that CDIO may have potential in entangling workplace practices with educational practices, but there must be a certain common understanding of when this is ideal to do.

It is tempting to think that by implementing CDIO the universities ensure that the students acquire the necessary skills for employment. This chapter shows that there is a great difference between what CDIO looks like on paper and what it looks like in the lives of the students and instructors at the universities. When the point of departure is structured standards, as is the case with the CDIO initiative, the outcome may be expected to appear structured as well. In the daily lives at the universities CDIO becomes enacted in many different forms, probably resulting in many different skills. The workplace and education do become entangled and therefore CDIO does achieve its goal, but not in the structured way the concept implies. When CDIO is enacted in multiple ways, workplace, education, theory. and practice will be enacted and connected in multiple ways as well.

NOTES

1 http://cdio.org/
2 http://cdio.org/cdio-vision
3 http://cdio.org/
4 To ensure the anonymity of the people involved in the studies, I do not mention specifically when I conducted the fieldwork at the two universities. The names of the people involved are pseudonyms as well.
5 Such as mechanical, electronic, software technology, chemistry, health care technology, building construction, and many more.pro
6 This fieldwork was part of my PhD study concerning theory and practice in engineering education. My focus here was wider than at ASE, but CDIO was still of great interest since the initiative relates to the topic of theory and practice.
7 Karl Weick has also used the concept of enactment. He developed the concept in relation to organizational theory and the theory of sense making (2009 [1988]). Weick's theory of organizations derives mainly from a social constructionist tradition and is quite focused on language. I try to move away from focusing on representation as the sole object of analysis and consider nonhuman agents as well. Also, Weick focuses on how organizations become enacted, which is a much wider focus than my narrow focus on a single concept. The enactments of CDIO might have effects on the organization, but the main focus is the enactments in practice. Also, Weick focuses on organization in singular. Mol's theory focuses on organizations as multiple: one organization is not enacted by humans' and nonhumans' actions; rather, these humans and nonhumans enact multiple organizations. I am not

interested in understanding how the organization is enacted, but I am interested in the multiplicity of a concept enacted within an organizational framework. I move on with Mol's definition since she focuses on multiple realities, which is a main point in exploring CDIO differently than how it is defined.

[8] Many names of instructors and students will be introduced during the analysis. It might be difficult to keep track of them, but this is not important. The position of the specific person is not important for the point I am making about various enactments of CDIO. CDIO can be enacted differently by all persons involved, and who is enacting is less important than what is being enacted.

[9] TA stands for Teaching Assistant. After or before each lecture, a two-hour session was organized to do assignments or homework related to the lecture. The students would work in groups or alone and the instructor and one or several TAs would be present to help them with the assignments. Usually the TAs would be students who had studied for more semesters, and Sebastian was a TA in some of the courses from their previous semester.

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NATHAN CANNEY

7. SHAPING FUTURE ENGINEERS THROUGH SERVICE IN ENGINEERING EDUCATION

INTRODUCTION

Modern engineering education sits at the intersection of diverse, complex and sometimes competing voices about the general need for more engineers and what skills those engineers should possess. Many are calling for the education of holistic engineers in order to address complex social issues being faced today (National Academy of Engineering, 2004; ABET, 2008; American Society of Civil Engineers, 2008). Though there are many approaches to achieving these goals, this chapter focuses on practices of Learning Through Service (LTS) as one viable pedagogical approach. LTS in an umbrella term which captures both curricular engineering service projects such as service learning and extracurricular engineering service engagements such as Engineers Without Borders (Bielefeldt & Pearce, 2012). This chapter examines first the goals of LTS including the environment and dispositions that it intends to create and second the career pathways of several alumni who actively engaged in LTS as students using a narrative analysis methodology.

A central emphasis of LTS is to create reciprocal and respectful relationships with community partners, where both technical and non-technical knowledge, beliefs and experiences are valued (Sigmon, 1979; Bringle, Clayton, & Price, 2009; Honnet & Poulsen, 1989). What, however, are the professional equivalents that students will engage in after they graduate? Examining the career pathways of alumni of LTS programs addressed this issue, focusing on how the skills and expectations that are developed, or at least supported, in LTS experiences may lack professional counterparts. Through the narratives of four alumni, issues regarding why students are attracted to LTS, what they find through their participation in LTS and how their professional pathways have been shaped by their LTS experiences are explored. These issues are examined because of the growth of LTS as an effective approach toward developing holistic engineers, but, with a potential lack of professional equivalents, perhaps students are being set up for dissatisfying or unfulfilling careers in engineering.

ENGINEERS FOR WHAT?

A driving question behind engineering education is for what should the engineer be prepared? Engineering exists to aid in the development of society. Directly under

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the Institute of Electrical and Electronic Engineers' (IEEE) logo are these words: "Advancing Technology for Humanity", supporting this central purpose (Institute of Electrical and Electronics Engineers, 2014). The issues that future (and present) engineers are being asked to address are increasingly complex. Issues of sustainability, environmental protection, declining resources, human health, as well as equitable access to energy, food and water are what many engineering professional societies point to as key issues for future engineers (Institute of Electrical and Electronics Engineers, 2014; National Academy of Engineering, 2005; American Society of Civil Engineers, 2008; American Society of Mechanical Engineers, 2008; American Academy of Environmental Engineers, 2009). Acknowledging the increasing complexity of the problems engineers are to address, many professional societies also acknowledge that the traditional focus of engineering education, predominately on technical skills, does not educate engineers with all the necessary skills needed to address them.

ENGINEERS FOR WHOM?

Engineers address global issues affecting all humanity. However, a growing concern is that the majority of engineering work being done today only benefits the top 10 to 20% of the world's population (Cooper-Hewitt, 2014; Michigan Technological University, 2014). The communities most affected by climate change, declining resources, human health and equitable access to energy, food and water, however, are not included in that 10 to 20%. If engineers are to earnestly engage these global issues, significant changes are necessary in the types of design work engineers do and the intended beneficiaries of their work. If the goal is to advance technology "for Humanity", as the IEEE logo suggests, then a broader view of who benefits from engineering design ought to be considered. Educating engineering students to identify, collaborate and design for the remaining 90% needs to be an integral part of the educational program for preparing successful engineers. So then, what type of engineer is needed to address complex social issues with openness to broader conceptions of stakeholders?

WHAT TYPE OF ENGINEER?

To address these complex problems and to engage a broader range of stakeholders, the U.S. National Academy of Engineering (NAE) set forth a vision for the engineer of 2020. That vision includes developing more holistic engineers who are capable of working in interdisciplinary teams across cultural contexts, who give full consideration to social issues and are ethically grounded (National Academy of Engineering, 2004). To educate this type of engineer, the NAE suggests that students engage in more open-ended problems, that active learning is employed in the classroom and that there is an increased focus on the development of professional skills (National Academy of Engineering, 2005).

Similar calls come from the engineering professional societies. The breadth of skills described in the American Academy of Environmental Engineers' (AAEE) body of knowledge (BOK) reflects this goal to train holistic engineers (American Academy of Environmental Engineers, 2009). Along with fundamental math and engineering knowledge, they highlight the ability to integrate sustainability into engineering solutions, understand the societal impact of public policy affecting engineering solutions and myriad other professional skills (communication, project management, etc.). The bodies of knowledge from other professional societies likewise have resulted in expanding lists of skills, beyond the traditional technical foundation. So does the Accreditation Board of ABET criterion 3 (a-k), which are used for programmatic accreditation at U.S. universities (ABET, 2008).

When the American Society of Civil Engineers (ASCE) examined which skills would be required to develop engineers capable of addressing these social issues, they focused also on attitudinal dispositions. An awareness of the development of attitudinal dispositions in students is necessary, recognizing that attitude affects the ways in which students implement the technical and professional skills they learn. Some of the key attitudinal dispositions cited include the consideration of others, fairness, respect, sensitivity, thoughtfulness and tolerance (American Society of Civil Engineers, 2008). The call for engineering education to aid in the development of these dispositions challenges even further the centrality of a technical focus.

The bodies of knowledge and other education related documents from the national academies and professional societies are the main mechanism through which the professional realm communicates expectations to the educational realm. It is worth questioning, however, if these documents truly represent the bulk views of the engineering community and companies or simply the voices of those professionals and educators who are passionate about educational reform. Do the attitudinal dispositions championed by LTS accurately reflect what recruiters at civil engineering firms look for in applicants or write about in job postings? Are these calls for holistic engineers reflected in the division of work and the company values that young professional engineers meet after graduation?

The need for holistic engineers, educated to gain a broader and more diverse set of skills, stems directly from the types of problems future engineers are expected to solve. Consider sustainability, for example. In order for a bridge to be sustainable, it must be properly situated. The challenge is to re-contextualize the bridge from an abstract bridge anywhere, which would require only a technical solution, to a specific bridge, serving a specific community, with specific resources. The social, environmental and economic considerations for such a bridge require that an engineer interfaces with the community in order to assess social constraints. The engineer needs to learn about the resources required for the bridge, perhaps giving preferential considerations to locally available materials. The engineer needs to weigh the implications of a short term versus long-term solution with respect to economic expense, but also environmental cost. To defend the final design, the engineer should interface with public organizations and effectively communicate how they considered the social, environmental and economic factors in their design, ideally arriving at a bridge, which embodies a balanced solution. This is a different type of engineer from the traditional perspective where, to quote a student I interviewed, *we don't need to understand why this particular society needs a bridge, other than the fact that they need a bridge, so we don't need to know anything about their culture, just, here's a problem.* The engineering profession acknowledges that "here's a problem" does not simply apply to the technical needs surrounding the bridge, but also includes public policy, social needs, environmental protection, resiliency, sustainability and many other 'non-technical' considerations.

LEARNING THROUGH SERVICE

Many educational approaches are being explored to find ways of incorporating more holistic training into the confines of existing engineering programs (Richmond, 2005). These approaches include teaching systems thinking (University of Colorado Engineering for Developing Communities graduate certificate), human-centered design (University of Washington Human Centered Design and Engineering program), or programs focused on engineering in development contexts (Colorado School of Mines' Humanitarian Engineering minor). Learning Through Service (LTS) is one such approach having positive results for both technical and professional skills development. LTS is an umbrella term which encompasses many forms of engineering service, including curricular and extracurricular forms. Two criteria are used to determine if an activity is included under the umbrella of LTS: there must be a community partner that is served by the exchange and the students must acquire skills, knowledge and/or affective outcomes (Bielefeldt & Pearce, 2012).

Curricular forms of LTS that tend to meet these criteria include service learning, Humanitarian Engineering, community engagement and community based learning. The common thread among curricular LTS activities is that the task students undertake in serving the community partner is directly related to the learning objectives of their course. These also tend, in engineering, to employ project based learning pedagogies as the basis of the interaction with the community partner. Some examples of curricular LTS projects include the design of a bicycle for a child with a physical disability, a playground design for a low income neighbourhood and a senior capstone project designing a waste water treatment system for rural coffee farmers.

Extracurricular forms of LTS tend to be through student clubs such as Engineers Without Borders, Engineers for a Sustainable World and Bridges to Prosperity. Similar to curricular forms of LTS, these activities tend to be project based. They can be domestic or international and they tend to include some form of travel to the project site for the student team. Though not tied to a specific course, many of these programs are still rooted in learning objectives and are seen as important elements of the bigger picture of educating engineering students (Bielefeldt & Pearce, 2012; American Society of Civil Engineers, 2008).

The key to LTS approaches for educating holistic engineers is that the projects are technically grounded and situated in context rich environments such that students must develop and employ a range of technical and professional skills in order to succeed. When done correctly, LTS projects engage students in the context in which the project is situated. For example, a current project that I am working on with students focuses on the design of low cost, sustainable housing for local seasonal migrant workers. For this project, students will engage with local and state legislative bodies, community activists, migrant worker families, local farmers and health workers in their search for an appropriate technical solution. In meeting and working with these groups, students are challenged to examine current social, cultural, political and economic norms around migrant labour, international trade, immigration, housing and legislation. Through this process, these students will develop both technical and professional skills and, hopefully, attitudinal dispositions which are in line with the vision for a holistic engineer, capable of addressing the complex problems engineers need to face.

Many studies have examined the benefits of student engagement in LTS activities, mainly curricular approaches such as service learning. The majority point to development in both technical and professional skills. One study surveyed undergraduate students across the US and showed that participation in service had positive effects on many academic and cognitive measures (GPA, writing skills, leadership, etc.), increased awareness of the world and increased awareness of personal values (Astin, Vogelgesang, Ikeda, & Yee, 2000; Eyler, Giles, Stenson, & Gray, 2001). A qualitative study of engineering students who spent four weeks in-country building a bridge found that students had positive gains in their technical abilities through their hands-on experience with the bridge, as well as professional skills of leadership, cross-cultural communication, global competency, teamwork and interpersonal communication (Jeffers, Beata, & Strassmann, 2014). Many other studies have shown similar findings through a variety of different methodological approaches and in a variety of settings (Ejiwale & Posey, 2008; Bielefeldt, 2006; Ariely, Banzaert, & Wallace, 2005; McCormick, Swan, & Matson, 2008).

The majority of LTS studies focused on the effects of curricular elements, typically service learning. There are, however, a rapidly growing number of extracurricular opportunities for students to engage in engineering service such as Engineers Without Borders (EWB-USA), Engineers for a Sustainable World and Bridges to Prosperity. Additional research has looked at student involvement in some of these extracurricular activities. One study has shown that students who participated in EWB-USA had higher perceived abilities in broad and holistic skills from the ABET criteria and higher expectations of their professional skills in their future career (Litchfield, Javernick-Will, Knight, & Leslie, 2014). Another study found that student participation in EWB-USA correlated with stronger views of social responsibility both from students self-selecting into these activities and also from engagement in the extracurricular activity itself (Bielefeldt & Canney, 2014).

In addition to the educational benefits, LTS activities are strong motivators for a sub-group of engineering students who derive enjoyment in the practical, hands-on and altruistic nature of LTS work, sometimes keeping them in engineering studies and professions when they would have otherwise left. Many students who participate in LTS activities talk about their increased interest in engineering through the work and how they enjoy hands-on, ‘real world’ projects (Litchfield & Javernick-Will, 2013). Others talk about how a desire to help others is what drew them to engineering initially and that LTS projects help them see that connection. Furthermore, other findings suggests that the increased focus on helping others resonates more with female and underrepresented minority students to choose and remain in engineering studies (Carberry, 2010; Duffy, Barrington, & Heredia Munoz, 2011).

Overall, research has shown that LTS as an educational tool addresses development in all of the ABET a-k outcomes (ABET, 2008), many of the ASCE BOK 2nd edition additional outcomes (American Society for Civil Engineering, 2008), as well as many of the attitudinal dispositions highlighted in the ASCE BOK (Bielefeldt, Dewoolkar, Caves, Berdanier, & Paterson, 2011). Additionally, the nature of LTS projects, be it the hands-on, ‘real world’ aspect, the service aspect, or the context rich aspect, seems to motivate students differently than traditional engineering educational approaches, helping in the attraction and retention of a more diverse population into the profession. These results point to LTS as an appropriate addition in the education of holistic engineers, able to address complex social issues.

It should be noted, however, that LTS is still an educational practice on the periphery in the U.S. engineering educational system. Curricular LTS is oftentimes employed solely based on individual faculty interests. Many efforts that have been made to intentionally spread service learning across an entire departmental or college curriculum are championed by one or two individuals and tend to wane as faculty move to other institutions or retire. There are, however, exemplars that have targeted LTS efforts such that students have at least one experience every year (e.g., Service-Learning Integrated throughout the College of Engineering (SLICE) at the University of Massachusetts – Lowell). Extracurricular LTS, however, is growing considerably around the country. EWB-USA and other student clubs are present and an increasing number of universities and seem to have stable or growing participation numbers.

A major concern, however, with the growing inclusion of LTS activities into engineering education is the interface between engineering education and engineering practice, specifically in the engineering students who were active in LTS efforts, graduate and then move into the professional sphere. There remain vast unknowns about how the skills and dispositions gained by students who engage in LTS in school are received in professional realms. Do jobs exist which mirror the LTS experiences, focusing directly on engineering for developing communities (e.g., World Bank, USAID)? Do students who engage in LTS even want those types of jobs? How do the skills and attitudinal dispositions which are fostered in LTS activities relate to the professional pathways which are available? While the engineering professional societies call for the development of more holistic engineers, is there really a place in the current professional climate for holistic engineers of the type that LTS creates? The answers to these questions remain largely unknown, but this chapter explores some of them through a narrative analysis of interview data from alumni of LTS programs.

PROFESSIONAL PATHWAYS FOR ALUMNI OF LTS

Thus far, this chapter has looked at LTS as a pedagogical approach that has the capacity to develop the type of engineer needed to approach complex issues such as sustainability, climate change and equitable access to food, water, energy and health. If educational systems are successful at creating this type of holistic engineer through LTS, it remains unclear what the professional pathways of such students look like and how engagement in LTS affects those pathways. This next section explores these connections through interview data with alumni of LTS programs.

Before jumping into an exploration of alumni career pathways, I want to first discuss the origins of many of the engineering LTS efforts, particularly the extracurricular ones. The desire for more direct and positive impact on people's lives came, largely, from students. The first EWB-USA projects at the University of Colorado Boulder were done through the collaborative work of Dr. Amadei and students. The rapid spread of EWB-USA from the University of Colorado Boulder happened largely due to students who heard about the organization, went back to their home institutions and started other chapters. Moreover, most professional EWB chapters were founded by employees, upon their own volition rather than through the company itself. In just 11 years, EWB-USA has grown to over 14,700 members, both students and professionals and continues to expand (Engineers Without Borders USA, 2014). Additionally, many of the curricular LTS efforts have come from individual faculty members who saw the importance of connecting engineering students with communities where their engineering abilities could have positive impacts. This is all to say that the push for the incorporation of service in engineering and engineering education has largely been a bottom-up movement, driven by motivated students, employees and individual faculty, more than top-down through professional societies, company mandates, or accreditation expectations.

Data Collection and Analysis

The empirical data used for this chapter comes from interviews with 19 alumni of undergraduate and graduate engineering service programs, such as EWB-USA or graduate programs focused on international development. These interviews were conducted as a part of a larger National Science Foundation funded study focused on the personal histories of engineering students and alumni with respect to their development of social responsibility. The interview participants were chosen from three different schools that participated in the larger study, specifically from students who faculty knew as very active in LTS activities as students there. Typically this meant students who either founded or were leaders in university EWB-USA chapters. Alumni were intentionally solicited to find participants who were on the fringes of the engineering community with respect to beliefs about service. By approaching alumni who were most active in LTS as students, the goal was to sample the extreme population that was most likely to have been positively affected by their LTS involvement. Therefore, this could not be considered a representative sample of the engineering population as a whole or even of a broader population who simply experienced LTS in school; this population self-selected into leadership roles in LTS and even continued studies through graduate programs focused on engineering and international development. This approach to sampling is similar to what would be used in a phenomenology study by sampling for shared experiences among an outlier group (Case & Light, 2011). Additionally, participants were intentionally selected to represent varying durations since graduation (i.e., different amounts of time working) and also different career pathways (i.e., traditional firms, NGOs working in development work, or left engineering all together). The alumni were contacted via email and the majority of the interviews happened over the phone or through online conferencing software.

A narrative analysis methodological guided these interviews and their analysis (Connelly & Clandinin, 2006; Creswell, 2007). The idea of pathways was examined, drawing from the "processual approaches" (Peacock & Holland, 1993) to narratives whereby these stories illuminate the self-formation, social relationships and self-other discoveries which are critical to examining how attitudinal dispositions associated with LTS affect engineer's career pathways. Through a lens focused on storytelling, the interviews were open-ended, asking participants to tell their story starting with their participation in engineering service in school, their initial job search at graduation and through their careers up to the point of the interview. They were asked to reflect on key moments in their path that led to their current positions. Follow-up questions were asked along the way to allow participants to expound upon motivations or perceptions that led to various choices in their career pathways. Consistent with the narrative analysis methodology, the interviewer did not shy away from contributing his personal stories, typically in response to participants' questions about the purpose and origin of the study.

For the analysis of each interview, the interviews were recorded and transcribed. In this chapter the data are presented as personal narratives for four interview participants, highlighting their actions, motivations and reflections on their engineering service and professional experiences. In reporting data from this methodological approach, it was important to paint a more complete story of a participant's pathway. For the cases presented herein, this included select childhood experiences that influenced the participant's self-selection into LTS activities in the first place. These experiences form a foundation from which their deeper involvement in LTS and subsequent professional pathways developed.

The four participants presented in the following were selected from the total of the 19 interviews because they each represent a different career pathway that was seen across the interviews, but, collectively, represent the majority of pathways observed across all 19 interviews. Because of the commonality of these pathways among the 19 interviewees, these four paths could be seen as representative experiences for this extreme population of alumni; those who were very active in LTS as students and then continued into engineering focused careers after school. From these data alone, it is unclear if these experiences are also representative of a larger population of alumni who were less involved, but perhaps also positively affected by LTS activities as students, though the purpose of presenting them here is to posit that these pathways may be more common than just among this population.

Philip

Philip's paternal grandfather was an expatriate who worked in Latin America, so Philip's dad grew up there and spoke fluent Spanish. This intimate experience with the Latin culture and language instilled in him a desire to affect change in these communities. In college, Philip began as a mechanical engineering major, wanting to be an engineer in Latin America to work on development projects. Philip soon realized that the majority of development projects he was interested in revolved around improving water infrastructure, so Philip switched into civil engineering with a focus on environmental engineering and water quality.

Philip became the president of the newly founded EWB-USA chapter at his school. He held this position for the first two years of the club, helping to develop and execute a water accessibility project in Nicaragua. He travelled to the site with a group of engineering students and professionals, commenting on the diversity of experiences and knowledge that the group had. He specifically talked about one participant who had worked in the Peace Corps on water projects for several years. Once the team arrived in Nicaragua, they discovered that the water distribution system wasn't broken, but that an upstream user was using the majority of the source water for an adobe brick making facility and therefore the community downstream was not receiving expected water. Working with the local NGO that installed the water system, the EWB participants and local residents went back to the original water contracts that were developed and resolved the issue. Reflecting on the experience, Philip commented on how inspiring it was to see individuals get water access in their homes and to be a part of making that happen.

As Philip was getting ready to graduate, he had already secured a job working for a large, international firm in a geotechnical engineering position. Philip worked logging soil samples on drill rigs. Because this position did not utilize his education as an environmental engineer, Philip left this job after a year and searched for another job doing environmental work. After several months of searching, Philip found a job in a small engineering firm focused on environmental considerations in extractive industries. Philip worked on projects with a gas and oil company, monitoring and developing remediation plans for chlorinated spills. Reflecting on this, Philip said, "I thought that was pretty cool because then I actually got to see and understand what all this training that I got (his engineering education), you know, how it actually reached people." He pointed back to his EWB experience and how it had helped him to recognize and learn to focus on the "end user" of small scale projects. Philip talked about what it was like being an environmental engineer that worked with extractive industries and, pointing to his EWB experiences, said,

> *Every job's got some hard pills to swallow, you know, even if you're working for a non-profit, you've got to give and take, … just provide the most positive influence where you can and if someone else were in this position or any position that I will be working in, perhaps they won't see things in the same way I will… I won't have had that opportunity to influence it in the direction that the EWB experience provided me.*

Philip stayed with that job for over six years, but then the desire to work and live in Latin America drove him to search for a new job. He again pointed to his EWB-USA experience as the catalyst, saying that his experiences in Nicaragua had "planted the seed" for his desire to do engineering in development contexts. He also pointed to his father's experiences growing up abroad and that he wanted to give those same experiences to his young son. Philip chose a large firm that has offices around the world and engages in many projects in Latin America, hoping to be sent there to live with his family and work on development projects.

Erica

Erica grew up enjoying the lake that her family home sat on. In high school, an invasive weed was introduced into their lake and rapidly destroyed the natural ecosystem. Seeing this, Erica was inspired to go into environmental engineering in order to "make a difference and work towards solving problems like this." Her exposure to water and sanitation issues in environmental engineering quickly led her to be interested in international development work. This aligned with her personality, which she described as being rooted in "a desire to help people", saying that she always wanted to "do something that makes some impact in people's lives" and that engineering was the path for her to be able to do that.

In her undergraduate studies, Erica was involved in several research projects examining the social impacts of environmental problems; one of these experiences took her to the University of Colorado Boulder where she was first exposed to EWB-USA. After that, she returned to her school and founded their EWB-USA chapter. She talked about how many of her classmates were originally drawn to EWB-USA "because of the travel opportunities, but once they got involved they realized, 'oh wait, this has a larger potential than just travel.'" She spoke about how once they realized how their work could help others, "they're hooked."

Erica went straight from undergraduate into graduate school. She had several offers with full funding, but chose a program where there wasn't funding but where her work would be focused on "small scale [engineering projects] that really made a large social impact", specifically improving access to clean water for developing communities. It was worth it to her to piecemeal funding from many sources, resulting in her working much harder in her graduate program, in order to do "something that I was passionate about."

Leading up to graduation, Erica began looking at consulting firms that did international work and also supported EWB-USA. While Erica wanted to work for an NGO and do small scale, large impact projects, she was advised to look at traditional consulting jobs in order to get the appropriate experience and to be "more marketable." A driving reason for selecting the firm she did was their support of employees engaged in EWB-USA, specifically an additional week of vacation to travel for EWB-USA projects. About this she said, *I knew that [development work] was something that I wanted to do in my life and I was going to be involved in EWB and it made sense that my company supports it as well.* For Erica, this was a significant selling point because it helped her to maintain a healthy work-life balance by not using all of her personal vacation time on assessment and implementation trips with EWB-USA. In addition to extra vacation time, the company supported employee involvement financially and emotionally through a positive corporate culture.

From the beginning Erica saw this as a temporary step on her way toward working on international development projects through an NGO or development agency. At graduation, Erica planned to work for five years, get her professional license and then move to development work. After five years, however, Erica realized that she needed more experience and planned to continue working at her current job. She admitted that it wasn't what she wanted to do for the rest of her life, but that, in order to do development work responsibly, she needed more professional experience. Regarding her daily work as an engineer, Erica said,

> *I'm getting the consulting experience [that] was recommended for long term career development, but what I do is not satisfying right now. But I supplement it by doing EWB. [Doing EWB on the side] is hard because, yes you're making an impact, but you might not be doing it as much as you want or helping as many people as you'd want to help. Your ability is limited by your nine to five job, but, from a career standpoint, do you want people out their designing stuff that don't have adequate experience?*

Tracy

Tracy was on a traditional engineering education path as she started her summer internship at the end of her junior year. At that point, she had not had any engineering oriented LTS experiences in school. She was offered an internship at a prestigious engineering firm that worked primarily in defense contracts. Her summer work there challenged her personally, making her question whether or not she wanted to continue in an engineering career; not because of the content of her work but because of the lack of context. She would ask colleagues why they were doing what they were doing and found that few people had an answer for her, but seemed satisfied with the technical challenge and were uninterested in the end purpose.

After returning for her senior year, Tracy heard about EWB-USA and decided to found a chapter at her university. For Tracy, this was the context she had been looking for in her engineering work and decided to finish her degree and continued directly into graduate school at the same university where she remained active in the EWB-USA chapter.

Nearing graduation, Tracy's EWB-USA experiences heavily influenced her career search. She said, *after starting EWB I pretty much knew that I wanted to do more international development work… I knew that I wouldn't be happy as a sort of traditional engineer.* After spending six months in South America implementing an EWB project and working on other water projects, Tracy returned to the U.S. and looked solely for jobs with firms and non-profits doing international development work. In searching for these types of jobs Tracy reached out to contacts she had made through EWB and soon found a job working with a company that fostered infrastructure development around the world. Tracy worked on a wide range of projects, from hydroelectric dams to micro-financing.

After two years at this company, Tracy decided to look for a job that used her background as an environmental engineer. Again, utilizing the contacts she developed through EWB, Tracy found a job as an engineer at a non-profit focused on environmental conservation and development. In this career, she discovered that as one of the few engineers in the organization she brought a unique set of skills and perspectives that, in her view, balanced the team and strengthened the organization toward appropriately weighing both environmental conservation and development.

When Tracy reflected upon her involvement in EWB-USA and how that affected her path through jobs in international development, she said

> *[EWB] was just one of those things that combined everything perfectly for me. I like being challenged, I like travelling, I like having to think on my feet… School is fine but I felt like I always got bored until I had a real problem to work on that had a reason behind it. Fit into that the fact that there were people we were working with and that we wanted to make their lives better. There was essentially no way that that would not be what I wanted to be doing… everything else had seemed very incomplete and [through EWB] I finally had a way or reason to be doing what I was doing.*

Sam

Sam started his undergraduate education as a pre-med and Spanish major because of his desire to help people. After taking some time off to travel and volunteer in

Latin America, Sam realized that the lack of civil infrastructure was actually the root of many of the challenges in developing communities so he switched to civil engineering when he returned to school. As a student he became active in EWB, saying *it gave me a venue to blend my interest in making the world a better place and my engineering skills… It was a way to use my engineering skills to help people.*

As Sam approached graduation, his plan was to work in a traditional environmental engineering firm for a few years to get experience before "coming back to doing more of the aid work." He took a job as an environmental engineer, preparing and reviewing environmental impact statements. Sam worked for two years in this position before he left. Many reasons led to Sam leaving his job and leaving engineering all together. He experienced negative "office dynamics and politics" and struggled with the long work weeks, often working over 60 hours per week. Sam also struggled with conflicts between his ambitions as an environmental engineer to help people and the often contradictory demands of his company's bottom line and that of their clients. Sam found himself *trying to argue for my clients doing less work in terms of remediating a chemical spill that they're responsible for* which sometimes became *…situations where I was asked to do things that I thought were unethical.* Knowing that he was not happy in this firm, Sam asked friends and colleagues at other environmental engineering firms and found that his situation was not uncommon. He reflected: *it seemed like it was a problem that was a lot bigger than just the specific place I was working.*

When considering what career field to move into, Sam reflected upon his travels through EWB and on his own in developing countries and in Europe. From his travels he recognized how the over consumptive culture common in the U.S. created inequity around the world. Moreover, from his travels in Europe, Sam saw that consumption, lifestyle and equity were choices a society made and he felt that the example he saw in Europe was that of a lifestyle which was more globally aware and conscience. He desired to help foster a similar cultural awareness in the U.S. With this goal in mind, Sam returned to school to study marriage and family therapy, with the idea that change happened first with the individual and that people couldn't change if they were too burdened with their own problems. After several years of practice, Sam felt that he was helping to create a greater sense of empathy in our society, thereby paving the way for radical social change that would hopefully create more equitable possibilities for people in developing countries.

Reflections on LTS Engagement

As students, all four participants spoke similarly about their draw to LTS, specifically EWB-USA and what their engagement fulfilled for them. Each of the four spoke directly about how LTS provided a space where they were able to combine their personal and professional aspirations, namely, a desire to help people through engineering. For Philip, his LTS experiences would 'plant the seed' that would drive his career moves over the next eight years, drawing him back toward doing development work in Latin America. For Erica, LTS showed her that engineering was the pathway for her to have a positive impact on peoples' lives. For Tracy, the ability to combine her passions and see the purpose of her work through LTS kept her in the engineering program and into graduate school. Similarly, LTS provided a space for Sam that aligned his desire to help others and his enjoyment of engineering.

These four alumni and others that were interviewed, also talked about how LTS helped develop skills for them that they would use later on in their careers. Philip talked about how his LTS involvement helped him to focus on "the end-user", which was something that guided him in his work as an environmental engineer. One interviewee cited the mentoring and teaching aspects of EWB as the reason for his returning to school, getting a PhD and becoming an engineering professor. Most of the alumni who worked at firms doing development work talked about how much of their professional work was non-technical and that their LTS experience helped them to develop those communication, grant-writing, mentoring and organizational skills.

Pathway Divergence

As students engaged in LTS, there was little in terms of motivation and views of LTS to differentiate the four alumni. Approaching graduation, however, their divergent pathways began to emerge, though, for most, their motivation and desires remained similar. All four alumni held a desire to work in international development work as they were graduating and looking for engineering jobs. Philip desired to do this kind of work in some way through his career, looking at traditional engineering firms to provide that avenue. Both Erica and Sam were advised to get experience working in traditional engineering firms before returning to international development work at an NGO or similar organization. Erica was advised that this would make her "more marketable" and that it would provide a safety net if she ever left development work. Tracy, however, fought to go directly into international development work and succeeded, in part due to the professional connections she had made through EWB-USA.

These diverging pathways bring up interesting questions. Why did Erica and Sam's mentors suggest that they get experience in traditional firms before doing what they desired, which was to work in international development. Were there not other career pathways available that would give them the experience and knowledge for development work, while actually doing development work? Should traditional engineering work be the only pathway available to gain this experience? Would working directly in engineering development work not give them the skills and experiences needed, as it seemed to for Tracy? Should Erica have to work in unsatisfying careers for five, six, ten years before going into development work or should other models exist that allow the training and experience to happen in development work contexts from the beginning? Despite being dissatisfied with her work, Erica seemed to agree that she needed more experience before doing development work. Sam, on the other hand, left engineering completely after his experiences did not support his vision of using engineering to help people.

Counter to Erica and Sam, Tracy was mentored and supported to go directly into international development work. As with all new engineers, Erica, Sam and Tracy all presumably learned a lot about how to be a professional engineer in the first few years of their job; Erica and Sam in traditional firms and Tracy through development work. Tracy, however, streamlined her pathway and spent that time learning directly the skills she needed to do development work, while Erica managed dissatisfying work by supplementing with EWB until she could do development work. Sam left engineering all together before making it to his goal of doing development work.

All four alumni held the same desire at graduation, which was to work as engineers in international development work. At the point of the interviews, only Tracy had been successful, having taken a direct route from school into development work. Both Philip and Erica were attempting to shift their careers toward development work through different means. Sam, on the other hand, left engineering after seeing that his professional experiences were in opposition to his desire to help others. The difference between Erica staying in engineering and Sam leaving could simply have been Erica's engagement in EWB as a supplement to her work. Both Erica and Sam had ambitions to get experience first, but found their professional work dissatisfying. Would advocating for both of them to follow professional pathways directly into development work have been better for them, potentially allowing Sam to stay in engineering and providing Erica with satisfying and fulfilling engineering work? How should mentors, advising graduating engineering students, advise them in career pathways? Is the idea of getting experience through traditional paths a misstep for those students who desire to do LTS-type work professionally?

Alignment in Professional Pathways

The core theme through all four alumni pathways is the desire to achieve alignment between their personal and their professional goals. Each participant held personal goals to help others. This goal was met in their engineering during school through LTS. As professionals, each of the four continued to strive for alignment between these goals, often changing jobs and sometimes careers in order to do so. Philip moved from a geotechnical firm to an environmental firm, in order to use his engineering degree more directly to help others. Philip's desire for alignment with his goal to do international development work continued to drive his pathway, leading him to a large firm where he hoped to be sent to Latin America. For Philip, he searched through traditional engineering firms, where he found alignment as an environmental engineer, but was still searching for the international development piece.

Erica found alignment between engineering and the desire to help others, not through her work as an environmental engineer, but through her involvement with

EWB-USA on the side. For Erica, having the support of her company to engage in EWB-USA was critical while she gained the experience she desired to leave her job for a career in development work.

Tracy's desire for alignment drove her at graduation to look only at international development work. In her first job she had the development work, but lacked the environmental engineering. This misalignment pushed her to move to a new job after two years where she had a better balance between her engineering and her ability to help others. LTS provided Tracy with the alignment she desired as a student and she worked fiercely to maintain that through her professional pathway.

Finally, Sam experienced severe misalignment between his engineering work and his ethical foundation, rooted in a desire to help others. After only two years, this led Sam to leave engineering all together and pursue another profession where he was able to more directly use his career to help others. The alignment that Sam found in LTS as a student lacked professional corollaries, which eventually led to his departure from engineering.

Tensions between LTS and Professional Pathways

The educational goals of LTS are to develop engineering students who use a diversity of skills, technical and professional, to work across disciplinary and cultural divides to solve complex problems. For students, LTS provides a space where they find a form of engineering that marries their desire to help others and passion for engineering, despite being simultaneously embedded in the narrowness of decontextualized technical courses. For some, the view of using engineering to help others aids them to persist to graduation and into professional engineering careers.

Examining these four cases as representative of the pathways of the outlier student who is excited by LTS raises issues about how the holistic engineer that is fostered by LTS may not have a place in most existing professional pathways. For those students who come to engineering out of a desire to help others and search for alignment between that desire and engineering, there seems to be difficulty in finding professional pathways to achieve that. For alumni who enter into traditional engineering careers, they seem to struggle to find alignment between these two desires, like Philip, Erica and Sam. Philip continued through traditional firms, finding enjoyment in the engineering work and how it positively affected people's lives; like through soil remediation. Erica found little satisfaction in their engineering work, but were able to find ways outside of their career to fulfil their desire to help others through engineering, such as through EWB-USA professional chapters. Sam was unable to fulfil that desire outside of their careers and therefore ended up leaving engineering in search of another career where they could help people directly. Finally, a minority of students, like Tracy, may decide to go against the traditional pathways and chose to start their careers in development work directly. Many of these students seem to enter into an unclear arena, struggling to get jobs and needing to blaze new trails into fulfilling careers that mixed engineering with the service to others. For those that succeeded, they seemed fulfilled in their careers.

For many alumni who had been positively influenced by their LTS experiences, as seen in these four cases, the follow up from school into fulfilling professional careers appears to be a challenge. The views of community involvement, direct benefit to people and desires to help others that is seen and fostered in LTS work in school does not seem to align with opportunities that are found in traditional engineering careers. For this subgroup of engineers, those who have been positively impacted by LTS and desire for alignment between a desire to help others and engineering, traditional pathways seem to lead to three paths: living dissatisfied professional lives, supplementing dissatisfying work situations with EWB professionals, or leaving engineering. Based upon this research, only a minority of alumni who desire this alignment find it through traditional career paths. In this way, LTS in engineering education sets up a tension by fostering an environment that connects engineering with helping others, whereas professional models oftentimes lack that connection.

CONCLUSION

This chapter has presented four cases of career pathways from among a subset of engineering alumni who self-selected into LTS activities as students, oftentimes drawn by a desire to combine their passion for engineering with their personal goals to help others. Presumably, these students were exposed to the holistic training that LTS promotes, building upon pre-existing attitudinal dispositions that led them to enhanced roles in LTS in the first place. This subset of students is used to exemplify how students who engaged in effective educational pedagogies used to develop holistic engineers move to and through professional paths in engineering. The intention is that these cases provide examples of what would happen if educational systems continue to strive to create more holistic engineers, but the professional engineering culture remains as it is currently. These cases provide a basis from which to examine that disconnect and to discuss where the call for holistic engineers is coming from, how to do this in education and how professional environments embrace or further support that type of engineer.

Therefore, is Learning Through Service selling a lie to engineering students? Say the engineering education system is successful in developing students who are proficient in math and science fundamentals, designing engineering experiments, communication, teamwork, leadership, ethics and many other technical and professional skills. In addition, these students possess positive attitudinal dispositions regarding the consideration of others, fairness, respect, sensitivity, thoughtfulness and tolerance and see the importance of strong and respectful community partnerships advocated for by LTS approaches. The question remains; how do the engineers with these skills fit into the current professional engineering environment? Are LTS engagements providing a sense of alignment for students and exciting them about career pathways in development work that simply do not exist for engineers? Should they exist? Is LTS setting up false expectations among engineering students about the degree to which their engineering careers will have a direct positive impact on society, especially for the other 90 percent of the world who are traditionally overlooked in most engineering outcomes?

If this disparity between expectations and realizations is true, then how does the engineering community rectify this disconnect between the environment created by LTS in engineering education and environments of professional practice? Is it the educational environments or the professional environments that need to change? This chapter argues that LTS is an educational approach which fosters the skills and perspectives that are being called for by many engineering professional societies. These skills are technical and professional, as well as attitudinal dispositions that can help educate a holistic engineer. The complexity of the social issues that engineers must interface with necessitate such diversity of skills and perspectives in order to work successfully across cultural, social, technical and economic barriers. The educational system is slowly rising to this challenge, but there seems to be few professional counterparts that embrace the types of engineers that LTS creates. LTS works to develop respect for community partners, the desire to consider all who are affected by engineering design and a focus on directly helping people through engineering work. There are few professional environments that seem to embody or foster similar goals.

If the holistic engineers who find connections through LTS in engineering that support their choice of career as students are to remain in engineering careers, there is a need for professional models to change, striving to accept and further develop the holistic engineers being fostered within modern engineering education. The fundamental view of what a quality engineer and engineering firm is would need to change. If macroethical issues such as sustainability, climate change and poverty were embedded in the way an engineer approached their work, firms would seemingly have to change the types of projects they took on, their overall approach to projects and what skills and dispositions they would promote and reward among their employees. It would seem that the development of holistic engineers would, necessarily change the entire engineering profession, creating more alignment between the profession itself and its core object of engineering work "for Humanity."

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PART 3

ENGINEERING WORK PRACTICE

ANDERS BUCH

8. IDEAS OF HOLISTIC ENGINEERING MEET ENGINEERING WORK PRACTICES

INTRODUCTION

Engineering education is found lacking by a large number of diverse critics who argue that it does not provide the necessary skills and knowledge. In the US and Europe, governmental bodies, industry, professional associations, educators, and reflective engineers have raised their concerns. However, there is no consensus regarding the exact challenges facing engineering education. The critics support their claims with diverse arguments and propose different reform initiatives (Buch, 2012). Some critics suggest that engineering education should pay more attention to business (Clough, 2004; ATV, 1997; ATV, 2000); others suggest that it should evelop a sense of professional responsibility within the students (Duderstadt et al., 2008; Douglas et al., 2010; Riley, 2008), and still others stress the importance of contextualizing technical skills and knowledge (Williams, 2002; Jamison et al., 2011; Buch & Bucciarelli, 2015; Bucciarelli & Drew, 2015). Though their motivations vary, the critics seem to agree on broadening engineering education and thus supplementing or integrating the technical and scientific knowledge with elements from the humanities and the social sciences. The critics thus agree that engineering education should not only provide the students with technical skills and knowledge – it should be more holistic. The learning practices, along with the skills and knowledge provided, should be relevant for the kind of problems and challenges the future engineers will face. The students should learn how to apply their knowledge in order to solve real problems in substantive practices, i.e., practices that unfold in relevant engineering work in the world we encounter. Thus, narrow engineering skills and knowledge are not sufficient on their own. The critics argue that real problems—such as sustainability, global warming, health, and security (www.engineeringchallenges.org) —are not cut out in the metrics of scientific disciplines and that problems often need to be re-conceptualized and framed in new ways. The problems that engineers will face in the future are often unique, complex, heterogeneous, ill-defined and even wicked. Past solutions will no longer suffice. In order to solve these problems, engineering education must develop a new 'breed' of engineers that are innovative, cross-disciplinary, collaborative, and holistic.

The ambition of this chapter is not to recapitulate, reiterate, or strengthen the critics' arguments for reforming engineering education. Instead, the ambition is to critically reflect on the viability of the general idea that reforming engineering

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education will indeed result in more holistic engineering work practices. Education is often rightly seen as a vehicle for changing practices. However, reform initiatives far too often settle with education and do not take into account how work practices are actually reproduced, sustained, and transformed (Kemmis & Grootenboer, 2008; Kemmis et al., 2014). By taking its point of departure in practice theory, this chapter sets out to examine and discuss how a new 'breed' of holistically educated engineers (and other professionals who adopt a holistic approach) fare in substantive engineering work practices. The goal is not to empirically evaluate the success of holistic engineering education or a specific engineering program, nor is it to evaluate the holistic merits of individuals. Instead, I want to problematize the widely held view that reforming engineering education is an/the effective means of changing existing engineering work practices. Drawing on an empirical study, the chapter aims to demonstrate that in order to change existing substantive engineering work practices, it might be necessary to change engineers' knowledge and skills, as suggested by contemporary reform proponents, but it is far from sufficient. Conditions and circumstances external to the reformed engineers' knowledge and skills are crucial if engineering work practices are to become more holistic.

The argument of the chapter will proceed in five steps. I will briefly (1) outline the theoretical and methodological focus and approach of my investigation. I then (2) sketch a competence profile of a 'holistic' engineering program that has the goal to educate engineers to better cope with substantive engineering work practices. (3) The empirical study will then be introduced by contextualizing the site of engineering work practices. In the analysis section, (4) I investigate how the engineering work practices play out and how these practices are prefigured amidst the material arrangements of the site. Finally, (5) I conclude my empirical study and explain its relevance for the chapter's claim that reforming engineering education might be a necessary condition for obtaining more holistic engineering, but far from a sufficient one.

FOCUS AND THEORETICAL APPROACH

This chapter establishes a conversation between empirical material and practice philosophy, in what can be called a philosophical empirical inquiry (Kemmis & Mutton, 2012; Kemmis et al., 2014:13). I use a conceptual framework developed in contemporary practice philosophy to analyze engineering work practices as they unfold in an engineering consultancy company.

On the empirical side, I have conducted observations of engineering work practices and described the unfolding in space and time of the involved actors' talk, actions, and relationships. The observations gravitated around a small team (four members) in a Danish engineering consultancy company, which is referred to here as Sarix. The team worked with the development and promotion of a new product: carbon emission accounts. I had the opportunity to follow the team for almost a year, spending approximately one day per week in their company. During this period I studied the publications and work notes of the team members, conducted participatory observations and formal and informal interviews, and worked with generative methods of investigation. In addition, I had the opportunity to identify and interview a number of actors adjacent to the team and individuals with opinions on engineering and engineering competencies in relation to environmental work. During the research, field notes were recorded and most of the interviews and attended team meetings were audio recorded. The interviews focused on diverse issues and themes. Some introductory interviews focused on the team members' life stories (Linde, 1993, 2009), while others addressed the day-to-day assignments and the work of developing climate accounts. Auto photography—i.e., photo snapshots taken by the team members of significant 'events' in their daily work and additional logs explaining the significance of their photos—were used as generative methods that structured the interviews (Pink, 2013).

On the philosophical side, I have used the theoretical resources of practice theory (mainly from the versions developed by Stephen Kemmis and Theodore Schatzki) to explore and question my observations. I will briefly introduce the central perspectives and concepts in practice theory here.

Through the lens of practice-based studies (Gherardi, 2012; Kemmis et al., 2014; Buch, 2015), the study investigates how substantive engineering work practices are being "done." Here I focus on how the practices involved in developing climate accounts are enacted. A practice theoretical perspective is not so much preoccupied with studying individual actors and actions (practice in the singular). Instead, the unit of analysis is practices (in the plural). Accordingly, I will not focus specifically on the actions of the individual team members, but rather on the activity of producing climate accounts. Practices describe the activities that actors are involved in and perform, – seen as collective endeavors. Practice theory claims that human activities should be studied by focusing on routines, doings, and values in use. Practices are thus seen as fundamental "carriers" of social phenomena.

Practice theorists study both practice and practices, but it is essential to understand how the terms are related, how they differ, and why practice theory is preoccupied with the investigation of practices. Schatzki has spelled out these different notions. One sense of practice denotes *...performing an action or carrying out a practice...* In this sense individuals are carriers of practices because they perform specific patterns of actions and thus enact the practices. But, more significantly, practices can also be seen as coordinated entities. In this sense a practice is seen as a ... *temporally unfolding and spatially dispersed nexus of doings and sayings* (Schatzki, 1996:89–90). One of the essential claims of practice theory is that the performances of individuals are linked and interconnected in specific ways that form durable nexuses of actions.

I have been inspired by Kemmis' (2014) and Kemmis and Grootenboer's (2014) notion of practice architectures (see Figure 1) in order to discern the doings, sayings, and relatings that constitute the practices within the field-site. Recently, a growing number of scholars have proven that Schatzki's and Kemmis' approach is valuable for the study of learning and educational and professional practices. The present study adds to this emerging tradition. By using a practice theoretical framework, I explore how substantive engineering work practices (Fenwig & Nerland, 2014; Rooney et al., 2014; Green & Hopwood, 2014; Hopwood, 2016; Kemmis et al., 2014; Hager & Lee, 2012)—here in relation to developing a carbon emission account—are performed by the four team members. This has allowed me to investigate how cross-affiliations and overlaps of cultural-discursive, material-economic, and social-political arrangements are woven together to form substantive engineering work practices.

The production of my empirical material has thus benefitted from Kemmis et al.'s (2014) elaboration of Schatzki's (2002) theoretical and methodological framework and I use their "table of practice architecture" (Figure 1) to structure and present my findings. The description of the practices focuses on the actual sayings, doings, and relatings of the actors involved in the practices (the central part of the table). The practices are discerned through the following four perspectives: (1) how the sayings, doings, and relatings are shaped by the dispositions (or practical understandings) of the actors; (2) how the practices transpire in practice landscapes (or among rules and material arrangements surrounding the actors); (3) how the activity is framed within the projects of the actors (the teleoaffective structures); and (4) how the practices are informed by practice traditions (or general understandings) in which the actors are embedded.

This philosophical analytical perspective thus sets out to understand (engineering) practices by reflecting on the doings, sayings, and relatings of the practitioners, and how they are configured in specific constellations in time, space, and history, through the abovementioned four components. Reflecting on the four components raises analytical awareness of discursive and historical preconditions of the site as well as the material arrangements that prefigure the practices. Furthermore, it is necessary to reflect on how power relations and social-political arrangements shape the way practitioners relate to one another. This conceptual framework honors the complexity and heterogeneity of the engineering practices under study and affords the practical methods to track and propel the investigation. Kemmis et al. draw attention to the dual composition of practices and how this duality constitutes both individual agency and structure in social activity. Practices thus have both an individual and an extra-individual dimension that simultaneously produce individual knowledge and identity on the one hand and social structures on the other hand. In this way, the practice perspective challenges us to reflect both the individual and the social elements in ongoing activities.

Although sayings, doings, and relatings are thoroughly interwoven in activity time-space, I will, for analytical purposes, present the study according to the conceptualization of practices presented in the following Table 1. Kemmis et al.'s practice lens helps investigate how the dynamics of practices are brought about by the interplay of sayings, doings, and relatings and how activity is transformed into integrative practices (Schatzki, 1996:98f) through practical understandings, teleoaffective structures, rules, and general understandings. It should be emphasized that the organizing phenomena of practical understandings, teleoaffective structures, rules, and general understandings should not be conceived as a priori principles or categories that are structuring human activity. They should rather be thought of as phenomenological categories, i.e., points of attention toward understanding how actions organize into practices.

Table 1. Elements of practices and practice architectures in the site (adaptation of Kemmis et al., 2014:38–39)

<table>
<tr><td colspan="4">Individual side ← Practice → Extra-individual side</td></tr>
<tr><td colspan="2">3) Projects/teleoaffective structures
How purposes and intentions expressed by practitioners direct activity</td><td colspan="2">2) Practice landscapes
How practitioners and objects are enmeshed and entangled in activity and how materiality, rules, and procedures prefigure actions by infrastructural sedimentations</td></tr>
<tr><td>Practitioners’ characteristic sayings</td><td colspan="2">← How sayings performatively enact a practice in semantic space through language →</td><td>Cultural-discursive arrangements</td></tr>
<tr><td>Practitioners’ characteristic doings</td><td colspan="2">← How doings enact a practice through activity and work →</td><td>Material-economic arrangements</td></tr>
<tr><td>Practitioners’ characteristic relatings</td><td colspan="2">← How relatings enact power and solidarity →</td><td>Social-political arrangements</td></tr>
<tr><td colspan="2">1) Dispositions/practical understandings
How actors are attuned to participate in practices; how they have a “feel for the game”; and how they know how to “go on”: practical knowledge, skilfulness, and appraisal of specific values.</td><td colspan="2">4) Practice traditions/general understandings
How current practice is enacted to reproduce or transform the traditions and history of the local practice or—more broadly—in relation to the traditions and history of practices that span multiple sites.</td></tr>
</table>

WHAT IS HOLISTIC ENGINEERING

‘Holistic engineering’ is by no means a well-defined term. It is, however, a term widely used by various actors to point to a different and better way of doing engineering. The study discussed below gravitated around a small team working within an engineering consultancy company. The team attracted my interest because the team members claimed that they were doing holistic engineering work; the managers in Sarix, the engineers in other divisions of Sarix, and the customers of the climate accounts likewise claimed that this team was engaged in holistic engineering work. However, it was quite difficult for the team members and management to explain what was meant by holistic engineering work, and when prompted to do so, they referred to a progressive educational engineering program in design and innovation at the Technical University of Denmark.

I will briefly provide an account of some of the tenets, aims, and ambitions of this progressive engineering educational program to illustrate the ideas about holistic engineering that informed the site. Reference is made to the program mainly because it rationalizes the discourse about making engineering more holistic, but also because two of the team members were educated in the program. The educational initiative construes the challenges facing the future engineers—and accordingly the solutions that this educational initiative aims to supply. The founders of the Design and Innovation program describe the profile of the graduates as including the following:

> *[…] the technical- and social sciences and a heterogeneous engineering competence covering three important dimensions:*
>
> - *Reflective technological engineering competences, which refer to the reform of teaching and integration of the core engineering curriculum that has been an important part of the design engineering education.*
> - *Creative, synthesis-oriented competences aimed at integrating technical and social components during the development of products, systems, processes and services. The education emphasizes the development of students' personal, creative potential, engagement and enthusiasm, professional insight and the mastery of methods.*
> - *Innovative, socio-technical competencies to be utilized in the creation and renewal of systems and situations where technical organizing and humans interact, and where complex, political decisions confronts the engineering field's way of modeling and optimization.* (Boelskifte & Jørgensen, 2005)

The educational program thus aims to develop integrative and synthesis-oriented competencies that defy traditional "mono-technical view[s] of engineering competence" (ibid.). Furthermore, the program aims to stimulate problem solving in "realistic contexts" and to engage the students in project-oriented work that construes the learning process in a line of interactions and experiences. The program was initiated in 2002, and in a subsequent evaluation of the program conducted by the founders, it was reported that employers "emphasized that the graduates have strong competences in relation to generating concepts, working and approaching problem-solving in an open and creative and yet very structured way. They are very user-oriented, while still maintaining focus on the product or the technological system to be developed. The graduates also uphold a strong culture of teamwork" (Jørgensen & Valderama, 2005:413).

In interviews conducted with the team members, the Design and Innovation program graduates characterized their educational background as holistic and explicitly referenced the program as an alternative to traditional engineering. Though neither the engineers nor the executives that hired the engineers could clearly define what being a holistic engineer amounted to, they had no doubts that the Design and Innovation program epitomized a valuable alternative to traditional engineering. Reached by educating engineers that are creative, synthesis-oriented, driven by real problems, not confined by disciplinary boundaries, and prepared to bridge technical solutions with social needs. One of the team members with a degree from the program put it like this:

> *We [the graduates from the program] have been trained to be jacks of all trades, so we easily pick up on complex tasks. We are not encumbered by disciplinary caveats; we just want to solve real problems, not just some technical part of problems. At least, this is how we want to be seen.*

THE SITE OF ENGINEERING WORK

Sarix is an engineering consultancy company that provides consulting services regarding environmental and energy issues, planning and construction of infrastructures, and developmental cooperation in relation to the third world. Around 1,300 professionals – mainly engineers – are employed at Sarix (the term engineer does in Sarix include people with other educational backgrounds working as consultants). The headquarters of Sarix is situated in the vicinity of Copenhagen in Denmark, but Sarix also has local offices in other cities in Denmark and many employees are assigned to projects all over the world.

Copenhagen was the hosting city of the international climate summit COP15 in 2009. This event spurred a lot of public and political attention regarding climate changes due to the emission of greenhouse gases into the atmosphere. Until this event, the conservative Danish government had given little focus to climate problems. In fact, the Danish government sponsored the prominent "climate change denier" Bjørn Lomborg (2001) and had made dramatic cuts in the public environmental initiatives. However, this all changed in the preparation phase of the summit in Copenhagen. Suddenly the Danish government withdrew its sponsorship for Lomborg's research and recognized the severe climate challenges we are facing. This change of policy toward the climate problems was accompanied by new visions regarding clean-tech and environmental services as drivers for economic growth and employment in Denmark. These visions and the high expectations in relation to achieving global agreements on climate issues helped create an atmosphere of optimism and encouraged the companies within the environmental service sector to launch new initiatives. This is the backdrop for the initiatives taken by Sarix in 2008.

The company decided to establish a new division with a focus on climate change. Previously, the team members told me that the company had been supplying services that were "reactive" in relation to climate change, e.g., planning and dimensioning infrastructure facilities that could deal with flooding. Now, a new division is tasked with developing "proactive" climate solutions, i.e., solutions that could monitor and reduce emissions of greenhouse gases and document the carbon footprint of consumers, households, products, companies, regions, municipalities, etc. A dedicated Chief Operating Officer (COO) was put in charge of this new division and he recruited what he termed a team of "holistically minded engineers" (that were tasked with developing new types of accounts that could specify business units' total carbon footprint by measuring the direct and indirect emissions due to the unit's activities. In an interview, he explained the decision to recruit holistically minded engineers as follows:

> *What is important for climate accounts is a holistic perspective. […] When I was put in charge of developing this method of climate accounting, then there were this new breed of engineers—they are called "design engineers." I recruited some of them because I think they have this…actually they were not really that well equipped to do hardcore calculative tasks, but they had this…they see things within a greater perspective: what is of importance and what is not important. Compared to traditionally educated hardcore engineers, it was really easy to train them to develop the method…* (Interview with COO)

The COO was struck by the fact that heating and transportation could only account for a fraction of the total carbon emission. Other components integral to companies' manufacturing processes have a considerable impact that is not accounted for. The account should thus, so the argument went, develop procedures that can measure the quantities of carbon emission due to a company's totality of activities. The COO longed for a law-enforced regulation of companies' carbon emissions. Emissions had to be dealt with by turning them into economic incentives. If climate quotas come to play an increasing role in the pursuit of emission reductions, more accurate climate accounts should be developed in order for companies to monitor their footprints.

However, the climate summit turned out to be a disappointment. No global agreement was established and many criticized the Danish government's handling of the negotiations that took place at the summit. The enthusiasm and optimism about the prospects of the clean-tech industry and the environmental service sector as drivers for economic growth faded. No prospects of regulation of companies' carbon emissions were in sight. Sarix's proactive strategy was put on hold and the enthusiastic COO in charge of the strategy left the company for a position within an environmental NGO.

When I entered Sarix in 2011, the social-political arrangement of the site had reconfigured the organization. The climate division was abolished and only a small group of four employees were engaged in developing and selling climate accounts. Although Sarix had given up the ambitious climate initiative, the group insisted on upholding the status of a team that was dedicated to develop climate accounts. The team was engaged in developing what they called 'proactive environmental engineering solutions'. Two of the team members had a formal engineering education from a technical university. However, in relation to the majority of employees in the engineering consultancy company, all four of the team members had unconventional educational backgrounds. One team member was trained as a geologist from a traditional research-oriented university in Denmark and one had an educational background in the social sciences from a Danish university (Roskilde University) that stresses problem-directed and group-based learning methods. Two team members, although having a formal engineering degree, were graduates from the progressive educational engineering program in Design and Innovation at the Technical University of Denmark described in the previous section. Despite their different formal educational backgrounds, all of the team members considered their work to be a branch of engineering. Actually, in Sarix, the term "engineering" was used for all sorts of technical activities, including the proactive environmental solutions developed by the team.

Their status as a team was tolerated, but it was made clear to the team members that their activities should be profitable—otherwise their jobs were in jeopardy. An insufficient number of customers were interested in Sarix's climate accounts. Therefore, to uphold Sarix's efficiency standard and account for their individual fulfillment of their workload, the team members had to sign up for work in other reactive projects within Sarix. The vision of proactive and holistic engineering professionalism was a guiding ideal for the strategy adopted by Sarix to become a major player in developing climate solutions. However, although the strategy was put on hold, in their sayings and doings the team members still shared the holistic visions and clung to their team structure.

ANALYSIS

Observing the team members' doings, sayings, and relatings, the work with climate accounts appeared in a number of the routines, activities, endeavors, and projects of the engineering work practices. Figures in economic accounts were linked to emission tables and the fit between the categories of the accounts and the emission tables were refined, nuanced, and optimized to ensure greater precesion. The problem was that the economic accounts often used very crude categories that did not fit the emission tables; furthermore, the emission tables in their abstract form were not sensitive to the specificities of the actual dispositions of the companies or municipalities that wanted climate accounts.

The team members were thus struggling to make a fit—either by refining the details of the economic accounts by having the companies and municipalities revise accounting principles and practices or by modifying and combining the elements in the emission tables. This work was primarily conducted by the team members running a computer program, but they often had to contact the companies and municipalities in order to retrieve additional and more specific numbers from the economic accounts. One of the team members explained thusly:

> *We have to make a smooth fit between the expenditures of the business units in the municipality and the emission tables. You really have to be both inventive and diligent to make the translations—there is no strict algorithm for this work.*

Team meetings were convened for an hour once a week. Here the team members mainly discussed how to find new markets for the climate accounts and how to market the product more effectively. No general discussions about the product or the relevance and added value of the climate accounts for the customers were entertained.

They explained their apparent difficulties with selling services to private companies with reference to the lacking legislative regulation of carbon emissions, and the team put their trust in the new socialist government to take initiatives. Although they deplored the general lack of interest in the climate accounts from customers, the meetings were mainly focused on enrolling dedicated environmental engineers within customer companies and municipalities to work as internal spokespersons that could advance climate accounts as a viable option.

During the fieldwork one of the team members—the geologist—faced the consequences of the demise of the climate strategy and slowly drifted away from the team. He engaged in what his fellow team members considered to be more reactive engineering projects in other divisions of Sarix in order to satisfy the invoicing requirements. Another team member—the one with the social science background—had to start working part time and supplement his job by teaching classes on environmental engineering at a university college. The other two team members—those with a background in the Design and Innovation program—kept their full-time positions but shopped around in other divisions of Sarix in order to fulfill their work requirements.

When reflecting on the engineering work practices in Sarix, the discrepancy between the rhetoric of the business strategy and the mundane doings and sayings of the employees is striking. Eventually, the proactive plan was abandoned, but the team members still entertained the ambition of promoting and developing the climate account. In what follows, I will reflect on the nexuses of the team members' doings, sayings, and relatings in order to investigate how their work activities are organized in practice architectures. Furthermore, I will reflect on how the practices are interwoven with the material arrangements of the situation in order to discuss how (material) objects contribute to the prefiguration of activity. Throughout this discussion, I will relate my account with characterizations of engineering culture drawn from the literature. The account of the practices will be presented according to Kemmis' delimitation of the interlinking of human activities with practices.

How Engineering Work Practices Are Made Intelligible by Practical Understandings

In characterizing the activities of the team members, it is, of course, useful to identify the skills and capacities that are involved in their actions. On a basic level, the participants in the engineering work practices know how to 'go on' (Cf. Wittgenstein, 1958) doing their business, how to identify and promote their tasks and projects, and how to respond to the challenges they are confronted with in their daily work. In this very basic sense, the participants have a practical understanding (Schatzki, 2002) or a 'feel' (Bourdieu, 1990) of what is the proper way of proceeding in a line of actions considered to qualify as doing engineering work. In this sense, a shared recognition or intelligibility must exist among the involved participants regarding what should count as reasonable responses to challenges, a feasible way of dealing with problems, etc. The domain of possible responses within a situation must be restricted and delimited in order for it to be intelligible as something—in this case engineering work. Not just any conceivable line of actions qualifies as doing engineering work. In engineering, it is thus a deep-rooted presumption that problems must be framed in ways that make them solvable by using the preferred methods and tools of the engineering profession. Basically, problems must be construed in quantitative terms; entities must be identifiable and amendable to physical manipulation, instrumentation, numerical calculations, causal explanations, control, etc. Thus, a fundamental presumption ruling the practical understandings of engineering practices is that of means – ends relations: a metrics of efficiency and control (Rabinow & Bennet, 2012).

It is evident that the team members were enacting a branch of engineering work that they described as holistic engineering: an approach that amended the shortcomings of 'traditional' engineering. The team members had a practical understanding of what it means to do engineering work and to be employed in an engineering consultancy company. Even employees without a formal engineering degree—i.e., the geologist and the social scientist—envisioned themselves as doing engineering work, albeit in a holistic way. In their efforts to develop climate accounts the team members were focused on developing a definable product that could be commodified and optimized according to technical specifications. The challenge of climate change that was identified in Sarix's business strategy was first translated and framed in ways that made it possible for the company to take a role in supplying (technical) solutions to companies and municipalities that either wished to or were compelled by legislation to reduce their CO2 emission. Furthermore, the team members were assigned in order to develop climate accounts as a product that could be purchased in a market in which climate accounts were supposed to be in demand.

The team members clearly recognized what would qualify as an engineering approach to climate change: providing technical solutions falls within this understanding; however, making political arguments about regulations on carbon emission does not. According to the business strategy's intentions, their initial job descriptions, and their practical understandings of how engineers are supposed to frame and solve problems, the team members went about their business developing and optimizing the climate account. The economic accounts of companies and municipalities were investigated and analyzed in order to break down general categories into sub-categories that were relevant in relation to types of (energy) consumption; emission tables were refined and specified in order to encompass these categories. In breaking down the economic accounts and refining the emission tables, the team members were dealing with problems that clearly exceeded traditional scientific standards of exactness and ideals of justifiability.

The job involved making broad estimates, applying pragmatic judgments about the reliability of the information at hand, and accepting that the climate accounts should be flexible in order for companies and municipalities to use them in accordance with their specific accounting practices. The COO shared as follows: *The* *holistic engineers know how to prioritize relevance over scientific rigor. Traditional engineers wear professional blinders that prevent them from seeing the big picture. The holistic engineers are much easier to train for the job than traditional hardcore engineers. They easily learn what to look for an d what to discard*.

Although it was evident that the team members were enacting engineering, it was also evident that their enactment of engineering was considered marginal or in some sense bordering on the periphery of what is considered to be engineering proper. Referring to the two formally trained engineers from the Design and Innovation program, the COO expressed this evaluation when he stated that, …*they were not really that well equipped to do hardcore calculative tasks*. This evaluation was shared by the team members themselves, and in the evaluation of the Design and Innovation program Jørgensen and Valderrama (2012, 413) also noted that, …*the graduates were ambivalent in defining their competences, since they could not point towards some specific discipline defined cores in their competencies*. It seems that the practical understanding of what it means "to do" engineering, which was also shared by the holistic engineers themselves, did not quite encompass the competencies of the holistic engineers—thus the ambivalence. The practical understanding of what it means to "go on" as an engineer is reproduced and supported by the institutional settings of engineering educational systems and the engineering culture (Kunda, 2006) that pervades engineering consultancy companies. When the proactive business strategy was abandoned, the positive evaluation of holistic engineering competencies was silenced as well. Once the business strategy no longer supported visions of holistic engineering, the predominant and culturally deep-rooted conception of what is involved in doing proper engineering was no longer seriously challenged. Only the two remaining holistic engineers in Sarix had ambitions about "going on" in different, i.e., holistic ways.

How Engineering Work Practices Are Structured by Rules in Practice Landscapes

A second phenomenon that serves to organize activities is of course the formal and explicit rules and instructions that the employees in Sarix adhere to and how these rules are sedimented in procedures and regulatory artifacts. These rules (and their materialization in technical artifacts) constitute the practice landscape. Such rules and guidelines are available both in relation to professional conduct and in relation to how the employees are supposed to perform in order to justify their work contributions to the company. Each and every employee in Sarix (except employees in management positions and administration) should be able to dedicate 75 to 80 % of his or her work hours to customer-financed projects. Time spent on other activities were considered and categorized as unproductive time. The employees at Sarix had to fill out an electronic time sheet and account for their work hours with respect to specific projects on a weekly basis. It was evident that the four members of the team were not able to fulfill this requirement. Therefore, to uphold the efficiency standard and account for their individual fulfillment of the 75 % profitable workload, the team members had to sign up for work in other reactive projects within Sarix. The requirements of the invoicing system limited the horizons of the team members to short-term projects that responded directly to customers' needs.

As mentioned earlier, one team member—the geologist—faced the consequences of the invoicing system and slowly drifted away from the team. He engaged in what he considered to be more reactive engineering projects in other divisions of Sarix in order to satisfy the invoicing requirements. Another team member was more faithful to his holistic engineering professionalism, but he had to start working part time and supplement his job with teaching activities. The two Design and Innovation engineers kept their full-time positions but shopped around in other divisions of Sarix in order to fulfill their work norms. Thus the general practice landscape embodied in the invoicing system encouraged an individualistic, non-reflective, and instrumental approach to engineering work and made it difficult to do holistic and innovative engineering. At team meetings the participants only had time to divide assignments among themselves and to reflect on potential customers to whom they could sell their existing services and concepts. No time was dedicated to develop new approaches or reflect on the viability of the climate accounts as a product or a service.

Sarix has longstanding and close relations to many public companies and institutions, but it seemed as if the market for selling climate accounts in the public sector had been exhausted. The team members had good contacts with engineers and planners within the public sector. Their contacts shared the professional enthusiasm for developing climate accounts that could function as a monitoring tool for environmental initiatives. When interviewing a project engineer in a public company that had implemented the climate account, he told me that it was very much up to him to convince the board to adopt climate accounts. He himself was already convinced about the benefits of the monitoring tool. The project engineer thus already shared the perspectives of the team and worked to advance the use of climate accounts.

However, the situation was quite different with private companies as it was very difficult to motivate private companies to develop climate accounts. Only a few had adopted climate accounts as an element in corporate social responsibility (CSR) strategies. The team members shared the opinion that legislative measures had to be taken in order to get more private companies to develop climate accounts; it was not sufficient to motivate the CSR officer alone. The practice landscape should change to support the holistic engineering practices. The four team members put their trust in the new socialist government that came to power in the fall of 2011; however, no legislation in relation to climate accounts has been introduced as of this writing.

How Engineering Work Practices Are Directed by Ends, Tasks, Normativized Projects, and Practice Traditions

A third phenomenon that helps organize activities is the teleoaffective structures of practices. Schatzki (2002) describes teleoaffective structures as "a range of normativized and hierarchically ordered ends, projects, and tasks, to varying degrees allied with normativized emotions and even moods." The teleoaffective structures of practices specify what ought to be done and what is acceptable to do in situations. The teleoaffective structures thus specify normative hierarchies of significance, relevance, and goals that inform the actions of people. These structures need not be explicitly conscious goals or ends in view for the actors, but should rather be seen as structural signifiers that give an overall sense to actions. Schatzki emphasizes that these structures are recurring effects of actions and should not be conflated with structuralist accounts.

The teleoaffective structures emerge when there is general agreement about what is acceptable or unacceptable to do in situations. The presence of teleoaffective structures does not exclude controversy or disagreement about specificities, but instead provides an overall sense of purpose and direction for the activities. The structures both produce the practice and are produced by the practice. When describing "object worlds", Louis Bucciarelli and Sarah Kuhn (1997) point to the following general objectives and goals that drive engineering practices: to *arrive at a design that is fixed, repeatable, stable, unambiguous, and internally consistent*; to *abstract from concrete situations […] is key to problem solving d to managing complexity within object worlds*; as well as to *look at a design, or at a collection of objects, and to see them as an abstraction to which scientific principles can be applied*. These observations of the overall goals that inform engineering work both to describe the overall teleology installed in engineering practices and clearly demonstrate the normativities, values, and virtues that actors subscribe to in engineering practices.

There is no doubt that Sarix's proclaimed strategy to develop and supply sustainable, proactive, and holistic engineering solutions also resonated with the team members. For the holistic team members, however, it does not suffice to "arrive at a design that is fixed, repeatable, stable, unambiguous, and internally consistent," although these standards must surely be honored. The object world of traditional engineering must be expanded to encompass user involvement, environmental concerns, criteria of sustainability, etc.—hence the holistic perspective. Although Sarix's strategy envisioned engineering to transcend the narrow confines of traditional object worlds, it was still held within the means – end relations of efficiency and control. The new ends, tasks, and projects envisioned by the strategy were in principle similar to the ends, tasks, and projects being pursued in traditional engineering object worlds—the only difference being that new parameters of sustainability and environmental concerns were now included. The strategy thus construed holistic engineering along traditional engineering objects worlds, only new sustainability parameters were to be amended to the driving objectives.

A final ordering element relates to the practice traditions or general understandings that are available to and shared by actors within a practice. The "general understandings," as the phrase indicates, are not proprietary of specific practices, but are generally shared orientations and outlooks that might be informed by political, religious, ethical, or ideological persuasions (Schatzki, 2002, 86). Although they are general, they are also active in structuring specific practices. Engineers, like all other members of a community, endorse certain religious, ethical, ideological, or political persuasions. Many of these may be codified in codes of conduct within companies or professional societies and associations (Poel & Royakkers, 2011), but they need not be explicitly stated to be conductive. These general understandings thus often span different practices and can make them overlap at specific junctures in history. The general understandings thus lay out an encompassing worldview that informs practices and shapes our socio(technical) imaginaries (Cf. Taylor, 2004; Jasanoff & Kim, 2015).

It is important to stress that teleoaffective structures and general understandings are features of practices and that these structures and understandings are amendable to changes as practices change. Individuals are not "cultural dopes" that blindly adhere to the structures of practices; individuals enact practices. To illustrate some of the normativized ends, projects, tasks, and general understandings of the practices that informed the team members' activities, it is useful to consider some of the empirical material that was produced through the exploratory life history interviews. In what follows, the team members, including how they construe their aspirations in relation to their engagement with environmental engineering work, are briefly presented.

One of the team members—John, who had a background in the social sciences—was raised in a conventional family with a middle-class background. Although there were no traditions of political discussions or activism in John's family, he took a stance in relation to environmental work very early. He explained that his "worst nightmare" is to end up in a job where he is not able to "make a difference." Doing work that brings forward "solutions" and that "affects" someone stimulates him. He enjoys interacting with customers and "handling" their needs. Technical details must not be the most important thing in environmental work and he finds pleasure in posing "silly questions" to engineers that "rest assured in the professional convictions."

Another team member—Henrik, who was trained as a geologist—has a working-class background and, in his own words, has "a very practical approach to work." Assignments and work have to be "concrete," and it is important that work deals with "solvable problems." In his vacations, Henrik is engaged as a volunteer in NGO developmental projects in the third world. His dream is to one day get a full-time job abroad where he can work with water supply projects. He had hoped that the job at Sarix could make his dream come true, but it is difficult to get these assignments without "an established CV."

Sebastian—who has an engineering degree from the Design and Innovation program—has already traveled the world. His father was an engineer who worked internationally and the family has traveled extensively. Sebastian has attended international schools around the world, but when he grew up, he decided to pursue military training in Denmark. After graduating from the military academy he wanted to become an electrical engineer. However, he soon discovered that this education was “too limited,” and after studying for one year, he enrolled in the Design and Innovation program at the technical university. It is very important for Sebastian to work in teams and to be part of “something that brings about something new.” It is also very important for Sebastian that work life is balanced with family life—he is the father of baby twins and he gives high priority to family life.

Nille also started studies in the electrical engineering program, but quickly switched to the Design and Innovation program. Sebastian and Nille have had a close professional career at the technical university and now at Sarix. Her parents both worked as executive officers within private companies and from childhood she was strongly stimulated to engage in “creative processes.” Her professional interests are in innovation management, but it is difficult to find space and opportunities to pursue such interests in “an engineering culture where it is the concrete that counts.” Nille’s ambition is to enroll as a PhD student and do research in innovation management.

Although it was evident to all four team members that they were doing holistic engineering work, none of them identified themselves with what they called “traditional engineering.” Henrik realized that he was doing traditional engineering work, but he thought that his background in geology made his approach somewhat different—a bit more “science based,” as he expressed it. Although Sebastian and Nille actually had a formal engineering education, they both saw themselves as atypical because they were trained to think in a more holistic way than traditional engineers normally do. John—the social scientist—stated that he had no particular interest in technical details, but preferred to work with “the big picture,” He believed that this made him an “exotic bird in an engineering culture.” Thus the teleoaffective structures that informed the activity of the team members were not totally aligned with traditional instrumental ends, projects, and tasks characteristic of engineering practices. Visions about creative processes, questioning conventional ideals about professionalism, making a difference, getting the big picture, etc. are foreign to the object world cosmology that Kuhn and Bucciarelli attribute to traditional engineering culture.

How Engineering Work Practices Are Prefigured by Material Arrangements in the Practice Landscapes

Practical understandings, rules, teleoaffective structures, and general understandings are significant structural elements that help us understand the constituencies and dynamics of social practices. However, social practices should not be considered as free-floating doings and sayings in an ideational social realm. On the contrary, social practices should be considered as embodied enactments that are situated amongst and in the midst of objects—in time and space of practice landscapes. Objects—and material arrangements in general—thus causally impact social practices in the sense that they prefigure and channel forthcoming activities (Schatzki, 2002, 44 ff). Material objects, technologies, infrastructures, etc. can thus render it easier or harder to proceed in various ways. Material arrangements can prefigure actions to the extent of excluding certain courses of actions and installing others as preferred modes of actions at particular moments in time. It should be emphasized that this notion does not claim that material arrangements determine, control, or in any absolute sense make the enactment of courses of practices impossible. The prefiguration of social practices by material arrangements makes the weaker claim that actions take place amongst material arrangements and that these material arrangements causally impact actions in such ways that it can turn out to be harder or easier to proceed. The material prefiguration of actions, furthermore, does not exclude the possibility that actors eventually can change or significantly alter prefigurations.

To illustrate how the practices of the engineers at Sarix were prefigured by material arrangements, let us examine more closely the invoicing system. As previously mentioned, a fundamental rule for the organization and management of work in Sarix is the principle of individual productivity measured in terms of the ability of the individual to invoice his or her activities. Every week every employee has to account for 75–80 % of his or her hours and link these hours to invoiced activities; the accounting was done by filling out timesheets on the employees' computers. It is the individual responsibility of the employee to meet these criteria and to account for his or her productivity. It was difficult for the team members to accommodate these criteria of productivity. Commenting on an auto photography, Sebastian said the following:

> *This is a screen dump. It is a picture from our intranet. By the start of the week we receive a reminder to fill in our timesheet—if we have not already done so at the end of the previous week. It is a constant parameter of stress and annoyance—especially if you have too few assignments. As you can see, the "Missing timesheets" says "1." It indicates that I haven't made registrations for last week. "Current week" says "0.00 %"—an indication of my inability to sell my work hours. […]*
>
> *The constant reminder and control of time is highly demotivating…*

The invoicing system is both a major issue of attention and discussion at Sarix and—as the embodiment of the management system in the timesheet—a significant material arrangement that interacts with and in significant ways prefigures the engineering practices in Sarix. The team members found the invoicing system troublesome and demotivating and believed it was a major obstacle for the enactment of their (proactive) professionalism. It is clear that the logic of the invoicing system rests on the fundamental principles of the market: productive work time is defined in accordance with the ability to respond to and fulfill customers' needs, i.e., to solve the problems that customers are willing to pay for—thereby installing an inherently reactive and unmediated logic in work.

Most engineering consultancy companies have a long tradition of structuring work in projects and managing work according to specifications laid out in the tenders negotiated with the clients. Strong price competition has made the profit

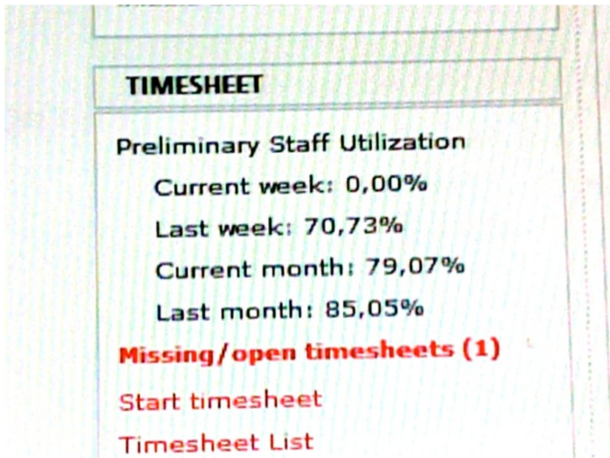

Figure 1. Photograph of timesheet (taken by Sebastian)

margins tight and hardly any room is left for innovative and experimental practices; only specified deliverables count. The timesheet embodies these principles and on a very concrete level prefigures the activities of engineers. By holding the engineers accountable in relation to the demands laid out by the accounting system, they must prioritize finding potential clients for the existing products and being efficient in supplying these products. Hardly any time and resources are left for innovative and reflective discussions of the viability of the climate accounts, e.g., the usefulness of the services in relation to private companies. When it turned out that not many companies were prone to implement climate accounts as ingredients in CSR programs on a voluntary basis, the team members put their faith in upcoming legislative intervention that would make it mandatory for private companies to account for their carbon footprint. The channeling of time and resources by the invoicing systems thus made it hard for the holistic team members on a practical level to come up with innovative solutions for promoting and innovating the climate accounts.

CONCLUSION

When zooming in on the relation between conceptions of engineering professionalism (conceived as a collective discursive construction) on the one hand, and how work practices are organized through the material-economic arrangements on the other hand, a tension is revealed. Spurred by the socio-political attention given to problems of climate change, Sarix embarked on developing a new and more proactive approach to climate challenge: It was not sufficient that engineering should handle the problems caused by climate change, e.g. flooding. Cultural-discursive arrangements in Sarix's strategy were aligned to fulfill a more proactive role, namely to develop climate accounts that could monitor CO2 emission rates and thereby prevent climate change.

This call could only be met if the engineering endeavor was redefined. Engineering should not be limited to solving specific and limited technical problems. Engineers should identify, measure, and deal with the causes of climate change in innovative ways. New engineering knowledge, skills, and competencies were thus needed to change the material-economic arrangements of the site. The engineers should have a holistic mindset and be able to frame engineering problems more broadly and in innovative ways. Borrowing a term from the literature on engineering challenges and engineering education reform, the engineers should develop a hybrid imagination (Jamison, Christensen, & Botin, 2011), critical thinking (Bucciarelli & Drew, 2015) and synthesis-oriented competences (Boelskifte & Jørgensen, 2005); in other words, they should "do" engineering differently. It was not sufficient to find technical solutions to climate problems; to prevent the deterioration of our climate, engineers should more (pro)actively engage with the socio-technical systems and find more encompassing solutions. By monitoring the CO2 emission of companies, the climate accounts could be an effective means of providing input to companies about their carbon footprints and thereby eventually motivating the companies to change their production practices and resource consumption in sustainable ways.

The cultural-discursive arrangements of engineering professionalism are thus developed around a vision about engineers as reflective, critical, and constructive knowledge workers who are able to frame complex and hybrid problems in order to develop new solutions. It was this vision of engineering professionalism that motivated the COO to hire Sebastian, Nille, Henrik, and John, and it is those cultural-discursive arrangements that inform the team members' ideals of environmental engineering professionalism. The empirical material of my study thus shows that there is an alignment in cultural-discursive arrangements between industry's demand for new engineering competencies and attempts to reform engineering education to become more holistic.

However, as my empirical material also indicates, the holistic ideals were de facto abandoned in Sarix after the COP15 disappointment. Only a small number of dedicated professionals tried to align their doings with the cultural-discursive arrangements and to uphold the ambition of providing proactive climate solutions; furthermore, these efforts enjoyed only limited success. Their activities were only tolerated as long as they were able to abide by the general material-economic arrangements and were productive and profitable for the company. It is easy and straightforward to explain the development in the site by reference to the social-political arrangements and the material-economic arrangements, i.e., the companies attention to business opportunities and their subsequent strategic reorientations when the political winds were changing and the markets turned out to be unprofitable.

My study thus tells a story about how holistically educated engineers (and other professionals with holistic ambitions) fare in non-holistic work practices. In delineating the engineering work practices according to Kemmis et al.'s and

Schatzki's conceptions, the investigation in Sarix firstly points to uniform and pervasive practical understandings of what it means "to do" engineering. It is apparent that holistic engineering work—as enacted by the team members of the study—only partially encompass the practical understandings in what they identify as traditional engineering practices. The team members describe their approach to developing climate accounts as atypical and partly in conflict with traditional engineering work practices. Secondly, we observed that the general rules of the practice landscape embodied in the invoicing system encouraged an individualistic, non-reflective, and instrumental approach to engineering work and thus endangered holistic and innovative approaches. Engineers were supposed to engage partially in many (non-proactive) projects simultaneously in order to fulfill their workload. Thirdly and fourthly, the general teleoaffective structures and general understandings of the team members seemed to be somewhat at odds with the ends and ambitions of the company (when the company's strategy changed). It was difficult to find room for their dreams, aspirations, and ambitions in relation to making a difference, working innovatively, and conceiving of work practices holistically. Furthermore, important material-economic arrangements and infrastructures, such as the computerized invoicing system, channeled activities in ways that did not stimulate collaborative and holistic work processes.

However, things do become more complicated when we reflect on the empirical materials' bearing in relation to reforms of engineering education. My study tells a story about the apparent discrepancy between the cultural-discursive, material-economic, and social-political arrangements in the substantive practices of engineering work. How do these points relate to questions about reforming engineering education? Reforming engineering education evidently fosters new engineering knowledge and skills and new learning practices, …*that is, practices whose project or purpose is to come to know how to go on in the substantive practices* ... (Kemmis et al., 2014). New learning practices can eventually contribute to changing substantive engineering work practices, but will not necessarily do so. As evidenced in my narrative, practices possess inertia and are influenced by more elements than individuals' dispositions, attitudes, knowledge, skills, and projects. The practice architecture of (substantive) practices is also determined by extra-individual elements, such as the practice landscape, i.e., the material-economic arrangements of the site, and the practice traditions/general understandings of the site.

Of course, engineering education reformers might object that this conclusion is trivial. Surely, no educator presumes that education alone does the job, and no educational reformer in her right mind would hold that there is a causal relation between changing the learning practices of individuals in more holistic ways and changing the substantive practices of engineering work to become holistic. While I fully agree, this objection does not render my conclusion trivial.

My study considers how professional work practices are changed (or not changed) and what kind of interventions bring about such change. My conclusion should be judged according to ethical and political considerations about the role and task of educators, reformers, and the companies that employ future engineers. Is it sufficient for educators and reformers to provide new knowledge, skills, and learning practices to students that might eventually, ceteris paribus, result in changing substantive engineering work practices at some point? Or, as my study testifies, should we instead acknowledge the fact that practice ecologies can be hostile to new types of practices and that things do not hold constant most of the time? Instead of witnessing new learning practices being suffocated in hostile practice ecologies, might it be the ambition of educators and reformers to educate future engineers to survive in hostile practice ecologies and provide them with skills and tools for trying to reflectively and effectively change substantive work practices in holistic ways? And what about the companies that employ future engineers? Should they just expect future engineers to fit into existing practice ecologies? Or should they strive to adjust practice ecologies to become more welcoming to new ways of practicing engineering more holistically?

It is my claim that practice theoretical studies can provide valuable analysis and information about learning practices and substantive professional work practices that can help educators, reformers, and employers to design learning and working practices that are more viable. In closing, let me provide suggestions for further research and directions for educators and employers.

The present study focuses on the substantive engineering work practices as they unfold in an engineering consultancy company; it does not include empirical material about the learning practices that unfold within engineering education, nor how learning practices and substantive work practices are in fact linked. Additional practice-based and longitudinally structured studies should be undertaken in order to trace the dynamics between engineering education and engineering work practices. Such studies must take into account and carefully examine the varieties of different practices that are enacted in the educational system and in different branches of engineering work. More specifically, it would be of interest to study the learning trajectories of students that engage in holistic engineering education and follow their transition into engineering work. This could illuminate how individuals are “stirred” into new practices and how individuals cope with conflicting demands. The present study shows that the holistically educated engineers’ (Nille and Sebastian) aspirations to make a difference and work more holistically were disappointed. Studying the practice traditions of engineering—as they are re-enacted in the educational system and in engineering consultancy companies, respectively—might lead to a better understanding of the ‘disappointments’ experienced by some holistically educated engineers that enter ‘traditional’ engineering work practices.

Understanding the specificities of practice ecologies—i.e., how different practices sustain, afford, or suffocate one another—could provide valuable insights to educators who aim to enable their students to make substantive work practices more holistic. Realizing that substantive engineering work practices can function as ‘hostile’ environments for holistic approaches could prompt educators to reflect on developing ‘double strategies’ that would make future engineers more robust and capable of coping with challenging practice ecologies, and would educate them to become change agents. Stephen Kemmis has ventured that practice-based studies of educational settings should be combined with action research methods: educators (and students) should become researchers themselves in order to change existing practices (Kluge & Negt, 2014).

Companies that want to restructure engineering work practices to become more holistic might also benefit from practice-based studies. Realizing that corporate rules, regulations, procedures, and material arrangements channel and prefigure practices in specific ways that make it easier or harder to enact them is valuable input. Understanding how the general practice landscape embodied in the invoicing system hampers holistic approaches and encourages individualism, non-reflectiveness, and instrumental approaches to engineering work might lead management to envision governance in new ways.

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RIKKE PREMER PETERSEN AND ANDERS BUCH

9. MAKING ROOM IN ENGINEERING DESIGN

INTRODUCTION

What are professionals up against when trying to reshape and revitalize current ways of doing engineering? How to make room for new perspectives and approaches? Is it enough to hire new types of engineers with different sets of competences? Or does it take something else to allow new ways of doing engineering to thrive in the workplace?

This chapter will focus on the emerging engineering design approach called user experience design and the practice's attempt to make room for itself within a traditional engineering organization. An individualistic focus does not account for the social and infrastructural barriers that arise when it comes to acknowledging and making room for new approaches and understandings. Our argument is that changing and renewing what it means to do engineering does not happen with the individual engineer or with new types of competences alone. Instead, it happens within the local ecologies of practices (Kemmis et al., 2014), that is, the constellations of different kinds of interdependent social work practices represented in the daily doings and interactions of a workplace.

The argument is supported by fieldwork conducted by one of the authors of this chapter. The fieldwork was undertaken at one of the major engineering workplaces in the Nordic countries: the Volvo Car Group. Within its extensive R&D, organization engineers work with all of the different sub-systems that make up a contemporary (and forward-looking) car. These include most of what we might call traditional engineering fields (such as mechanical and electrical). Here, however, we are interested in what happens when a new type of engineering approach is added. How does that challenge the established ways of doing – or ways of developing a car in this case? We have therefore focused the study on a small group of newcomers in Volvo's User Experience Competence Center (or simply UX Center). Judging from the individual educational profiles, our group is a cross-disciplinary one; at the same time, their collective approach might be seen as a new way of doing engineering design.

ENGINEERING DESIGN

In a Nordic context, the UX approach to engineering design is still new and, in some respects, emerging. In Denmark, engineering educations that stresses including user

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experience in engineering design processes have only been available since the early 2000s. Engineering design is, however, an established branch of engineering that can be characterized as follows: "Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym et al., 2005:104).

In some parts of engineering, the design part has been strengthened through inspiration from the traditionally more creative and synthesis-oriented industrial design tradition and most recently by a more socially informed design perspective (referring to different strands of user-focused design approaches, Dym, 2005).

User-oriented design approaches are therefore just some of the current efforts to push the engineering profession as a whole beyond a delimited focus on technology and science, thereby expanding the very core of engineering. The particular strand discussed here draws explicit attention to contextualization of technology – or what we might call a holistic perspective (Buch, 2016) – and emphasizes the human element in technological functionality – or what we might call a socio-technical perspective (Bijker, 2006).

The holistic and socio-technical perspective are not widely accepted as central tenets of the engineering profession, but user-oriented engineering designers find allies in closely related fields with similar interests – e.g., a more established trend in software development that focuses on usability and interaction design (Bødker et al., 2000, 2008) (i.e., also the strong relation between technology and user). While the field of user experience (UX) is traditionally linked to software development and interaction design, it has found relevance across a broad spectrum of development efforts. The UX approach to design work therefore cannot be linked to a single profession; we therefore choose to see it as a professional work practice, carried out by people coming from diverse educational backgrounds, as reflected in the empirical material represented here. What is of our interest, however, is whether UX practices can find room among existing engineering design practices.

WORK PRACTICES

It is one thing to have an overall understanding of what engineering as a profession is, but another to have an understanding of what that means for the day-to-day work of engineers. Wherein does engineering expertise actually lie?

Looking at professional work practices can help us build such an understanding. As Gherardi (2012:8) points out: *Work is much more than an activity undertaken in order to achieve a predetermined purpose.* Engineering work also embraces understandings of how to act in certain kinds of situations, principles and explicit rules to abide to, and an overall purpose of engineering work (Buch, 2015). As Reckwitz (2002:250) puts it: *A practice is thus a routinized way of which bodies are moved, objects are handled, subjects are treated, things are described and the world is understood.*

Practices are, generally speaking, an organized constellation of people's various activities (Schatzki, 2012). Practice theory studies these activities, how nexuses of activities are linked together, and how materiality is related to the social (including the human body). It is therefore not the actions of the individual professional (engineer) that are of interest here. Practices are social phenomena that are reproduced over and over with greater or less deviation in concrete situations. Practices are relatively stable phenomena, because people tend to hold on to what has already been established as acceptable.

As Nicolini (2012:7) points out, *Practice theories do more than just describe what people do. Practices are, in fact, meaning-making, identity-forming, and order-producing activities*. A practice is a way of doing that one can participate in or carry out to a greater or lesser degree. The individual can therefore be seen as a practice carrier (Reckwitz, 2002): *the practice perspective suggests that engineering should be studied as an ongoing practice of day-by-day skillful and goal oriented social and material reenactment of procedures and (codified and tacit) rules* (Buch, 2015:8).

We explore how carriers of engineering design practices struggle to make room for their user-oriented approaches in the practice ecologies of the site. Kemmis et al., introduced the concept of ecologies of practices, noting, *Our theory of ecologies of practices makes us carefully attentive to how the particulars of one practice, as it unfolds, creates practice architectures for other practices that are also found in particular sites. Our attention is not on how different participants co-inhabit a site, but on how different practices co-inhabit and co-exist in a site, sometimes leaving residues or creating affordances that enable and constrain how other practices can unfold*. Like Kemmis et al. (2014:43), we are interested in such co-existence of and interdependence between practices in the workplace and how that affects the introduction of new user-oriented engineering practices.

APPROACHING PRACTICES

In order to build an understanding of engineering design practices, we have chosen an empirical approach that enables us to capture, unfold, and understand not merely individual actions, but also the situations in which engineering design work takes place, via local social activities, heterogeneous relations, and resources for activities. As such, our focus on practices privileges an ethnographic, case-study-based research design (Trowler, 2014).

The practice perspective also implies that the practices we are interested in are always located at particular sites and performed at particular times. They are real in the sense that they do not make up an ideal form in themselves, or are performed on the basis of predetermined scripts. Instead, they unfold at a site shaped by particular historical and material conditions (Kemmis et al., 2014:33). A site is therefore not just a container of happenings (as the idea of "context" often suggests) but plays an integrated role in what can and does take place there, or as Schatzki (2005:468) puts it, *A site is inseparable from that of which it is the site.*

The first author of this chapter carried out a multi-sited ethnographic study of engineering design over a period of one and a half years in Denmark (Marcus, 1999). At one of the sites, the enquiry focused on the concrete accomplishment and re-production of engineering design work in a professional design project, carried out by a team of so-called UX designers within Volvo's UX center in Copenhagen. (The material presented here has been reviewed and accepted by Volvo in accordance to the agreement that was made with the first author prior to the fieldwork) At another site, the enquiry was oriented towards another UX team's strategic initiative to influence the wider organizational structures in Volvo in order to create better channels for UX perspectives and priorities in day-to-day work.

The sites were approached with participant-observations at the UX center roughly every other week. During the visits, priority was put on carefully listening and actively looking, engaging in natural conversations, writing detailed field notes and taking photos (visual notes) of situations. This ethnographic approach made it possible to build a gradual understanding of the interactions between participants and to start capturing the everyday details and the general understandings represented here.

Based on this material and on formal and informal interviews with members of the two teams, 11 episodes were developed. From this work, four concentrated episodes will form the empirical foundation of this chapter (The first author carried out the fieldwork. For further insights of the methodological approach of the study and the remaining episodes, read and use Petersen (2015) as reference).

USER EXPERIENCES AT VOLVO

The Volvo Car group, which focuses on development of passenger cars, employs a variety of professions within a classic organizational structure. The Design department mainly employs industrial (car) designers, the R&D departments employs various types of engineers (from mechanical to software), and the Marketing department employs people from a business and marketing background.

The majority of Volvo's R&D work takes place at the main office in Gothenburg, Sweden. Here, the Design department works on the overall shape and expression of the cars; the different engineering departments in R&D work with their respective sub-system of the cars; and the Marketing department works with selling points and customer segments for the individual cars and clusters.

In 2011, a group of UX designers (along with many other developers) were left unemployed when Nokia was forced to close down their development activities in Copenhagen, Denmark. The management in Volvo saw an unexpected opportunity in this to explore the opportunities afforded by a user-focused development approach – a growing trend that could help strengthening the Volvo brand.

There were some initial issues regarding where to place such a group of people in the organization given that UX design was such a new territory for the otherwise technology-driven car company. Eventually the group was placed as a sub-department of the HMI & Infotainment Attribute Centre – a department focusing on the increasing digital components in Volvo's cars and the accompanying interfaces. Physically, however, they were placed at a small satellite office in Copenhagen in order to accommodate a wish not to uproot the UX designers' families.

The individuals we find at the center have a mixture of educational backgrounds ranging from electrical engineering, industrial design, and multimedia to engineering design.

Jonathan, (all names are pseudonyms) who has a BSc in engineering in multimedia technology and a MSc from an IT university, is one of these UX designers. During the field visits in 2013–2014, he was engaged in a project referred to as the Daily Commute in a team with four of his colleagues (Cheng with a BEng in electronics and computer engineering, Carl with a BSc and MSc in design engineering and product development, and Melvin with a degree from a Danish design school). The Daily Commute project focused on the commuting experience (to and from work) in large cities such as Chinese metropolises. With this project, the team took the first steps of concretizing the vision for the future generations of Volvo cars that would be launched 2–4 years later. The UX team uses a so-called experience map or UX journey to make a physical map of the commuting experience, based on some existing and initial research. But the UX journey map is also a methodological approach to structure insights and identify the positive and negative impacts on the car's user during the trip, which can then be turned into design opportunities. They produce a short three-minute video to communicate the vision and point to design opportunities to be explored in a later conceptualization process.

ENGINEERING DESIGN IN THE EVERY DAY

In the following, we will present two condensed versions of the episodes witnessed during the field visits related to the Daily Commute project. These episodes illustrate how understandings are re-produced in local scenes of activities, how different practices meet in the everyday, and how they work together more or less successfully.

Episode 1: Working on a User Journey Map

After the morning meeting, the UX team turns their attention to the large paper wall in their project room. They were not all part of working with the wall yesterday, so Melvin starts out by explaining the main journey stages that have emerged: at the top of the wall some of the columns in the huge chart have received a yellow post-it note with a sentence stating which stage in the journey it now represents. Pointing to the columns, Melvin explains that they have left some open for now, as they expect more of these "journey fragments" to emerge as they continue their iterative process. Going through the rough outline of the day in the life of the Chinese commuter that they are depicting, they also start developing the main character, his age, and job – something creative, perhaps? Jonathan picks up a small orange post-it pad from the table and starts placing these on different parts of the wall's content to indicate things that need clarification.

One of them brings up that the nature of the different things they want to show in the video is quite diverse: some parts are technology-heavy, some have to do with building the main character, others showcase the different roles that the main character takes on during the day (husband, farther, employee, son-in-law). They are already starting to develop new situations that might occur during the journey – maybe he wants to pick up his kids from school despite the heavy traffic, or maybe his wife suddenly arranges an evening with the grandparents. "This taps into the values," Cheng remarks when they start adding new post-its to the top of the wall.

They all work in parallel adding post-its to different parts of the wall. Jonathan has started making some green "pleasure" post-its. He now steps back and asks, "What exactly do we refer to with 'pleasure'?" They discuss whether this is linked to the eventual proposed solutions or the instances of the journey at hand, as they see and hear it take place. In the end, they agree that this term is closely linked to the values they are starting to map out underneath (Figure 1).

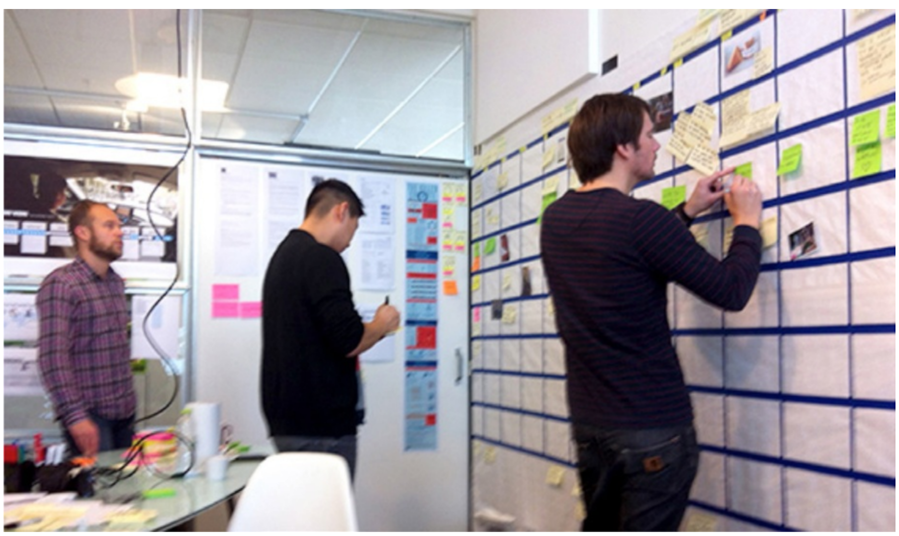

Figure 1. Parallel team interaction with the journey map on the paper wall

During this process, new design ideas also emerge – the car might be able to receive updates from the user's wife's smartphone or include projections of afternoon traffic jams when the users plan the trip home. To the sound of markers writing and post-its being torn off, Carl, who is participating via a video call, cries out from the computer screen on the table, "Remember to add these things under 'ideas'!" Jonathan and Frederik both grab some post-its in the appropriate color to comply with this right away. As he is writing up such an idea, Frederik remarks that they also need to start thinking visually: "Some of these things are hard to explain," he points out. Looking at the growth of the paper wall, he continues, "This is a lot for three minutes!" The others nod and agree that the decided length of the video also poses some serious restraints on what they will be able to show. This leads them to discuss the balance between making the video visionary but still realistic – how much should they push what they want to showcase?

Re-Producing Understandings

Throughout the UX team's work on the Daily Commute project, the paper wall, which the team interacts with in this episode, turns out to be the most important work surface. The UX journey emerges on this paper wall consists roughly of a horizontal timeline, mapping the different touch-points between a user (the driver) and the car during the commute, from morning until evening. For each event – or journey fragment – on this timeline, the team then comes up with ideas about "pains" and "pleasures" the user might experience and how new design solutions might improve or support them. This is a collective mapping exercise, where they collect their insights from different sources and generate new ideas.

In these situated activities, we get an idea of the understandings, the directionality, and the normativity embedded in the practices that the UX designers re-produce in interaction with the paper wall. Their way of working together reflects an appreciation for collaboration and mutual exchange of ideas. It also reveals their focus on the driver of the car and suggests that the car itself is just one of the things that affect the user's everyday experience, both positively and negatively. The UX designers also exhibit practical understandings of how to start developing the video (their immediate goal), how best to organize and retain their thoughts and progress, how to share knowledge between the individual team members, which tools are useful in this work, and so on.

What takes place at the UX center does not fall within a classic understanding of engineering expertise. Instead, we may see it as a bundle of UX-related design practices carried by engineering designers, IT engineers, and industrial designers alike into the UX center. It is interesting to note that at this local level, the engineering designers are indistinguishable from the other professions represented. Instead, they are joined together by their common project of building user understanding and translating this into technical solutions for coming generations of Volvo cars.

From this first episode, we can detect that interests from other parts of the organization also find their way into the project room and the team's considerations. The video they will produce is not for them, but must take part in a dialogue across the R&D organization. When the UX designers consider how visionary the video should be, the answer has to do with the video's audience – some parts of the organization are more interested in exploring future scenarios and some are more focused on what is doable in the next generation of cars.

The second episode regarding UX practices occurred as part of the same project.

Episode 2: Preparing an Inter-Departmental Workshop

On Friday, the team will be hosting a workshop. Jonathan explains that people from both “upstream and downstream” in the organization will be joining. This is the first time the UX center will be facilitating such a gathering, structured around a “journey.” In preparation, Carl and Jonathan have been continuing the work on the paper wall and have tried to cluster some of their design ideas – but more work is needed before it is presentable.

Getting started today, Carl immediately notes, “There’s a new pink one!” referring to a new row of post-its that have emerged on the wall since he last participated. The big piece of paper lining the wall of the project room is now more or less completely covered in colored post-it notes. Each row of the huge chart seems to have its own type of content: at the top, rough sketches are now depicting fragments of the journey with a central scene and event. Under these are short outlines of what’s happening and who’s there, printed on white paper. Then, shifting focus from a future-scenario perspective to present day, the next row lists what would happen in the respective scene today, followed by a row outlining what the users want (expressed as goals and values). The team has also mapped out the “pains” and “pleasures” relating to each scene. At the bottom, they have placed their identified “design opportunities” on the pink post-its (phrased as “how might we…”) and below that are different ideas for accommodating these opportunities. But there are still post-its floating outside the chart itself (Figure 2).

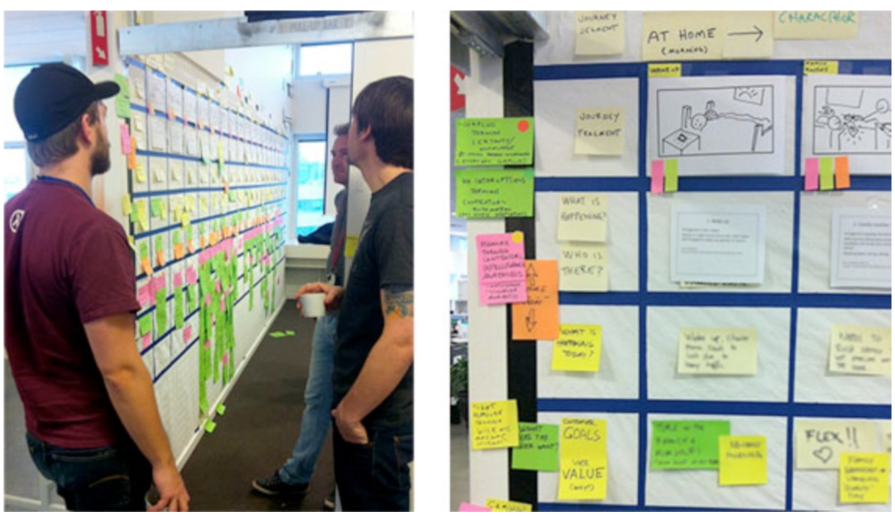

Figure 2. The UX team in front of the updated journey map discussing a mediating level (left) and a detail from the map (right)

The ones now forming the center of the team's discussion are three notes placed at the very edge of the wall. Jonathan explains that he and Carl made these particular post-it notes yesterday in an attempt to formulate some overall "value boxes" that they want to use at the workshop, in order to introduce the participants to this vast wall of thoughts. Each of the three notes have been given a small sticker in red, green, and yellow respectively, and these stickers appear on some of the pink post-its, denoting design opportunities. Cheng, who was not part of formulating these, asks for an example. One of them reads, "Pleasure through contextual intelligence/awareness." In Cheng's opinion, this is a very high-level statement that could refer to nearly anything. Carl starts to offer his take on an example for each of the three post-its, but during the discussion they agree that they should find a different format. As the rationale goes, if Cheng (who is part of the team and a UX designer) does not understand it, then those coming for the workshop (who have not been part of the process and are not familiar with UX) will certainly not understand it.

Right now, however, some of the team members are needed elsewhere, so the team dissolves. But Carl and Jonathan quickly agree to continue working on the journey wall for a while. However, they have not yet focused on the journey map itself, but instead on some of the post-its hovering above it.

Carl leans his head back to read from a few of them, pen and post-it pad in hand, ready to add some more. It seems they want to make another attempt at formulating some key features, to help the workshop participants gain an overview of the rest of the wall's display. They use the pink design opportunities to think through what overall categories they have used during their process so far. The wording is carefully considered before writing it down on new post-its as concisely as possible (for example, "getting there," "family," "parking").

Cheng rejoins them after a short while, scans the handful of post-its that Carl and Jonathan have already placed at the top of the wall, and asks what these are to be called: "themes?" Going back and forth, they do not quite land on a definition, but instead end up engaged in a conversation about how this new level fits in-between the very broad "Key Communication Points" (KCP), which are defined by the Product Planning department for the initial car cluster, and the more detailed journey outline below. The two KCP's placed at the top of the wall read: "Uncomplicating people's lives" and "Pleasurable in all situations." They all agree that these intermediate-level headlines will resonate with the delivery-focused department heads (Figure 3).

When they have reached saturation, Carl starts splitting up the post-its in two groups, one relating to each KCP. He physically moves the post-its, discerning between practical (relating to the first KCP) and more emotional (relating to the second KCP) elements. Seeing this new clustering, Jonathan suggests that they arrange it as a continuum, which will give room for those headlines that are in-between the two KCPs. He draws a rough sketch of what he means on a post-it; Carl proceeds to move the post-it clusters next to each other and starts sorting the

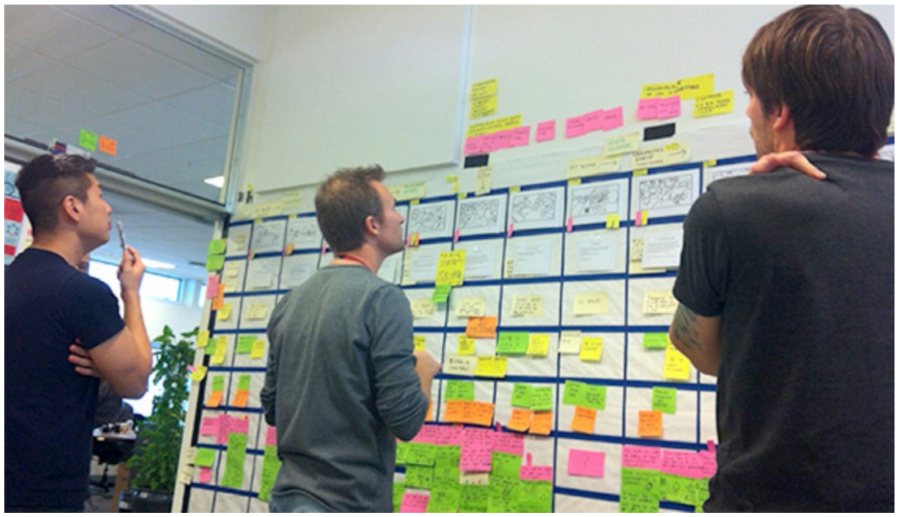

Figure 3. The team working to relate the Key Communication Points (KPI) at the top of the wall to the journey

in-betweens. While reviewing the post-its, they discuss whether some should be split up or rephrased. Having done this, the participants now come to a standstill, considering their next step. As lunchtime is approaching, they agree to take a break and to try later to map design opportunities under these new headlines, creating an even stronger link.

Relating to Other Practices

In this episode, we hear that inter-departmental workshops have emerged as informal meeting points, bringing together people from different departments ranging from "upstream" (long-term strategic planning) to "downstream" (specification and technical implementation). The team is aware that by arranging a workshop with participants from very different levels of R&D, they have also invited people who work differently, who prioritize differently, who speak differently, and so forth. In short, people who participate in different types of professional practices than what we find at the UX center (both in terms of engineering and otherwise).

Until this week, the team's process has been very open and explorative, focusing on generating ideas for scenes, developing design opportunities, and coming up with ways to depict the pieces of contextual knowledge gathered through interviews, etc. Now, when the participants are faced with presenting their work (even if provisionally and informally), they prioritize pausing the creative flow and making the wall more approachable and readable to outsiders.

The UX designers already have a feel for the different understandings they have encountered throughout the organization. Practice carriers bring practices together in the context of everyday life, not in isolation. Some practices work together and become mutually dependent, while others, like the different practices found across Volvo's departments, may be more conflicting and challenging to bring together. However, not only do the UX designers wish to bring their work into play in the other departments, they believe that their way of working can help bridge the work of the "upstream" and "downstream" departments.

Regarding their relationship to the Product Planning department, Jonathan explains, *They do some pretty overall descriptions of what a new car model should do – very general. It could be 'active city life-style' and 'dynamic driving', which is quite hard to translate into something concrete. So we get these general descriptions from them and then we can try to move it forward into some concepts. And then there's another interface, which is those who actually have to do some concrete implementation of it [the design opportunities].* The UX center therefore takes on a mediating role between the broad strategic formulations emerging from the business-oriented Product Planning department (for example, in the form of the KCPs) and the people in charge of implementing the design in the cars (the specialized engineers working with technical specifications).

What Is at Stake?

While the management may not have had a clearly formed strategy as to how the UX perspective would influence the overall way of developing new cars in Volvo, we can take the investments made in the new UX center as an indication that the holistic design perspective successfully speaks to some central business requirements. Which are creating products that prospective buyers see as a valuable addition to their lives and keeping users happy (or even positively surprised) when interacting with the product.

Organizationally speaking, the UX designers' work is to feed into the efforts of developing the dashboard region of the cars and the digital content; however, their fundamental understandings urge them to take a much wider view. The challenge is that a holistic, socio-technical perspective like UX design does not work as a mere add-on to existing ways of developing technology. Instead, it significantly challenges the fundamental technology-driven perspective that has so far been the cornerstone of car development. Within the UX center, we can witness a commitment to working towards much broader implementation of their design approaches in the rest of the (R&D) organization; for instance, the head of the UX center indicated that they would like to work with the car as a whole.

The engineering designers in the UX center are therefore proponents of a transformation of currently dominant engineering practices. Practices, where the world is understood and described through technical requirements and specifications;

where testing of functionality and optimization of components are part of the routinized ways of handling objects, and users are treated mostly as elements distracting the optimal operation. These elements are all crucial to making a car function in a simulated environment, but perhaps less so when it comes to developing a car that provides a comfortable and enjoyable driving experience in the everyday chaos of traffic jams, screaming kids in the backseat, and a lack of available parking at your destination. That is, an experience during which the technology does not take precedence over the user requirements it has been designed to support.

Challenging such a fundamental understanding, which runs through the very heart of an organization like Volvo, is no small task. A large R&D organization contains significant structures with well-proven ways of doing things and exchanging input. Thus far, they are slowly influencing the department in which they reside, as indicated by the subsequent change in name to the Digital User Experience Attribute Center (from HMI & Infotainment Attribute Center).

From these episodes, we learn how UX designers work to make room for their efforts, in relation to the other types of (engineering) work that takes place within the organization. Through their contact with other departments, they gradually find opportunities to meaningfully bring their input into play. This process is, however, not as simple as it may seem from the last episode. Because the UX designers are new to the organization, as is the type of input they provide, they are moving into already existing networks of relations and structures with well-proven ways of doing things and exchanging input. In the following, we shall take a closer look at these structures.

ENGINEERING DESIGN IN PRACTICE ECOLOGIES

A relatively new unit (founded in 2012), the Daily Commute project is the first time the UX center has been involved in the design process from start to finish – up until then, they had mostly been in charge of user tests at a much later stage. Therefore, the UX designers are developing (and negotiating) this new approach along with the rest of the organization.

Sebastian, who has an MA in film and media studies from Copenhagen University, was the second designer we followed during the field visits at the UX center. He was just starting work on a project referred to as the Umbrella Project (so called because it was made up of several components). In this project, he worked as part of a team with three others (Ella, with a degree from the business school; Tristan, an interaction designer from the IT university; and Lucas, a design engineer from the Architecture and Design program at Aalborg University) and by himself on specific sub-tasks. This project aimed to make more room for what we now might call UX practices within the Volvo organization.

By now, we may recognize how many different practices co-exist within an organization such as Volvo (and beyond), forming relations of both interdependence and competition. We might recognize these as ecosystems or ecologies of practices

(Kemmis et al., 2014). Looking at ecologies of practices means recognizing the networks of interrelationships between practices, which implies that the unfolding of one bundle of practices can leave residues or create affordances (sedimenting in infrastructures) that enable and constrain the unfolding of other practices – just as different parts of living ecosystems relate to one another interdependently.

In the following, we will present two of the episodes experienced in relation to Sebastian's work, illustrating how the efforts of making room for user-oriented approaches to engineering design unfold in a multifaceted texture of interconnected practices (practice ecologies), material arrangements, and institutional infrastructures.

Episode 3: Modelling Development Efforts and Roles

Sebastian sits at his desk and allows himself some time to look at the material that has been sent out in preparation for the team meeting later that day. The first attachment is a slideshow full of process models: one illustrates an interaction design process, and another is a model of a user-centered design process adapted from an ISO standard. Sebastian's first step is to do a quick search on the web for this ISO standard, which he does not know off-hand. He quickly finds a webpage where a similar model is shown and notices that it is a standard from 1999.

One of the slides also contains a model of a more traditional linear stage-gate process, overlaid with the steps of a user-centered approach. He continues through the slides, trying to form an understanding of the material. After a while, he decides to look for a presentation from an introduction course, which he attended when starting at Volvo – he explains that he remembers seeing a model in these slides, but does not recall the exact phases represented in it. Quickly scanning through this old slideshow, he finds the model that he is looking for: he remembers its distinct V-shape. Looking at this model again, there are a few things he did not realize at the time, which now strike him as helpful to understanding the new models.

He returns to the user-centered model, where four primary boxes are connected in a circular movement. The model is represented on three different slides, each with a different heading and minor changes in the different boxes. He toggles between these three slides before moving on to the second slideshow attached to the email.

After lunch, the team meets up in one of the meeting rooms. Ella, who has called the meeting, wants to keep the others in the loop on her efforts in Gothenburg. She explains that she has been attending meetings these past weeks, mainly to discuss processes and what she calls "hot topics." Sebastian asks who "we" are, and she explains that it is representatives from several R&D departments (Ella being the only one to participate from the UX center). These meetings have arisen after something she refers to as "the crisis workshop" that HR facilitated for the Infotainment department earlier in the year. Apparently, many of the employees had expressed a lack of motivation in their work, so they are now engaged in making responsibilities clearer and in developing a better work environment throughout the organization.

Ella now turns to the first slideshow that she sent out. The starting point is a description of the interaction design process. She also shows the more formal "back-end process," displaying the many gates with which Volvo typically operates. But there are differences in the way the different departments work. Ella explains that in her experience, the Design department works more iteratively, whereas the Software department works more according to "the waterfall model."

Ella then skips forward to show the ISO standard model of user-centered design. She openly wonders why "the Gothenburg group" has chosen this as their starting point for developing a new model, but "it is supposed to be iterative." Sebastian is now able to provide information about the ISO standard based on his preparations before lunch. He explains to the others that the standard is from 1999 and that its stages match well with those represented on the slide: there are four overall boxes with "understand," "define," "design," and then finally "evaluation."

The three versions of the model that had confused Sebastian earlier are supposed to illustrate one iterative cycle each, Ella explains, starting with "pre-concepting," "concepting," and then "implementation." In her meetings, participants have come to agreement on the different aspects listed under each of the boxes (such as who provides what kind of input, and when) in the different iterations. But that has been – and still is – a long process.

Overall, Ella seems skeptical of the models emerging from the process – "Where is the agile?" she asks. According to her, the person leading their process does not think in terms of agile processes or of "sprints," as they do at the UX center. Sebastian then asks if anything in the models prevents an agile approach Tristan also wonders about the temporal aspects in the models – the labels given to the three cycles of iteration seem to him to indicate a gate-to-gate focus (which can span several months), "but the agile elements are more at a biweekly interval," he points out.

Identifying Infrastructures

In this episode, a bi-departmental effort is taking place in order to develop and agree on a process for the development work, which helps delineate different roles and responsibilities. A central part of these efforts is to define what, when, and how things are passed from one (sub-) department to the next. So far, a straightforward stage-gate model has guided the work and deliveries.

Stage-gate models are popular tools to manage, direct, and control product innovation efforts and reduce the time from idea to market. With this model, the innovation process is subdivided into a number of stages during which certain efforts are carried out, separated by 'gates'. Each gate is characterized by a set of deliverables, a set of exit criteria, and an output. Arriving at a gate, the project leader must bring the agreed set of deliverables to be judged against the exit criteria. The outputs are the decisions made at the gate, which is typically about whether or not to let the project continue to the next stage (the "Go/Kill/Hold/Recycle" decision). Work is accomplished during the stages and the gates ensure that the quality is sufficient and that the direction of the project matches the overall strategy of the company (Cooper, 1990).

In a company like Volvo, which works with complex technical products with many sub-systems, the stages typically consist of several parallel processes carried out in different departments, and different deliverables are brought together at the gates; it is only here that they may affect the requirements set up in the other sub-systems.

The stage-gate model therefore supports traditional engineering practices and in turn may hamper other approaches, such as the UX designer's more agile approach.

This episode therefore introduces us to some of the established structures we find within the Volvo organization, and to the residues from dominant practices that create affordances for other practices. The stage-gate model, for example, has emerged as a crucial backbone for coordinating time allocation, requirements, specifications, presentations, and assessments across departments. From the practice perspective, the model defines and maintains some of the interfaces and relations between the different professional practices across the R&D organization and into the higher management levels and the separate Design department.

Gherardi (2006) points out that *The normalcy of organizational life arises from relations of connecting in action, and this connective texture is taken for granted when the alignment of ideas, persons, materials and technologies holds together.* As the stage-gate model has been translated into a number of procedures to follow, documents to submit, and underlying agreements to fulfill, it has come to frame day-to-day doings within and among individual departments.

Though the infrastructures are normally transparent (Star & Rudleder, 1996), the UX designers come up against – and become familiar with – the structures, all the while becoming more fully-fledged members of the Volvo organization. In the organization's daily work, as we saw in Episode 1 and 2, the UX designers need to relate to these infrastructures (e.g., by making specific types of deliveries at predefined times) and find ways to unfold their practices.

In creating the UX center, Volvo has added a new bundle of practices to the existing ecosystem of the organization, which necessarily creates new tensions. The UX designers are now working to adjust to their new setting at Volvo; at the same time, they also hope to influence this setting by negotiating what counts as engineering expertise. They either need to make room for their practices within existing infrastructures, or 'convert' to the practices currently supported within the organizational structures. In the final episode, we shall look at how the UX designers aim to create space for their practices.

Episode 4: Challenging Existing Structures

Tomorrow, Sebastian has a one-hour meeting with two representatives from middle management in the R&D organization (including the director of their department). At this meeting, he needs to ensure buy-in from the rest of the department cluster by presenting the condensed recommendations of the proposal he has been working on. He is surprised that he has succeeded in setting up this meeting the week before Christmas, which to him indicates that their efforts hold some priority to those higher in the organizational hierarchy.

Slightly removed from the rest of the team, Sebastian has been charged with developing a proposal for tackling so-called seed projects in the future. The aim is to come up with a procedure for capturing good ideas (the "seeds") in the organization and help bring them into actual projects. The team's hope is that this procedure can be introduced throughout the R&D organization, not only in their department cluster.

At this point, Sebastian has developed an extended slideshow of the proposed seed process, descriptions of all the elements involved, and an executive summary. When talking to the managers tomorrow, he will make sure the executive summary is as crisp as possible, enabling them to focus their decisions. Having worked on this content on and off for some weeks, he is confident that he will be able to answer all questions that the managers might have.

One slide outlines the purpose of the seed projects – as Sebastian explains, he must be explicit about its purpose from the start in order to ensure participants' collective agreement, before moving on to discuss the details. One of the first points on this slide states that the new seed projects will not be focused on technology development. Sebastian is a bit concerned that the managers might question this focus; he knows at least one of the managers would prefer the technology development projects to be part of the initiative. He explains that at Volvo, they are currently employed in two overall types of development projects: car programs, where new generations of cars are developed, and research projects, where new opportunities are explored.

The car programs themselves consist of many stages and typically span several years. However, they operate within a fairly locked development trajectory (framed by the stage-gate model), which does not leave room for new innovation to enter along the way – or as Sebastian puts it: *the readiness to accept 'new solutions' is greatly reduced for each gate that is passed.* Each year a pool of money is also allocated to research projects, now primarily focused on maturation of new technology, which may take years to make functional and involves high risk (the technologies may prove unfeasible or be overtaken by new developments on the market). These projects are also managed through stage-gate models. Only a small part of the research funds is allocated to other types of projects – a circumstance that the UX team wishes to change with their seed proposal. The goal is to take over half of the research budget. However, for this to happen, the team's processes and structures need to link to the existing structures.

In order to explain how new research projects are typically initiated, Sebastian draws three overlapping circles on a piece of paper. The first he labels "customer," the second "technology," and the third "business." As Sebastian understands it, the UX designers are working within the customer domain, but he mentions that the marketing people and the test drivers at Volvo also see themselves as representing the customer. In the business domain he places, for example, the Brand department and talks of strategies. New research projects, however, typically come from the technology domain, whereas with the UX team's seed proposal, they aim for more research projects to emerge from the customer domain.

Returning about a month later, Sebastian's focus had shifted somewhat. He was now looking more concretely at what could be done in order to get this new process started in a pilot phase. To do so, Sebastian detailed the organization's research funding structures. He contacted someone from the management team to learn when the budget negotiations would take place. In reply, he received a graphic outline of what is called the "Annual Factory." Sebastian has pored over this document and is now able to discern it: "we are the blue ones," he says, and "here and here are where we must deliver something" in order for the management team to include their new efforts in the yearly resource allocations. He explains that this process is governed by some cross-organizational councils that decide which projects should be allocated a budget (Figure 4).

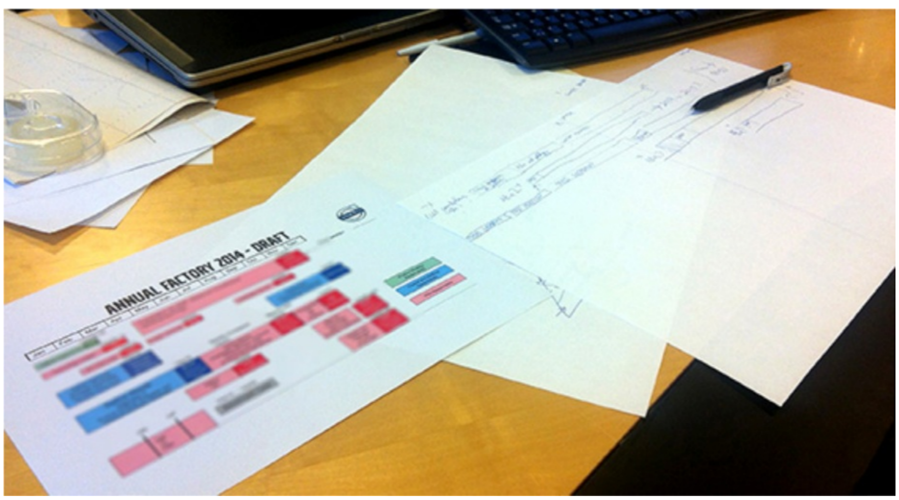

Figure 4. The 'Annual Factory' document and Sebastian's first attempt at planning the piloting phase in accordance

Pushing, Bending, and Expanding

In this episode, Sebastian engages in the delicate process of making room (specifically in the research budgets) for their user-oriented design approaches, which prioritizes qualitative knowledge of the users and early user tests in an organization otherwise dominated by a technology-driven approach. As he explains, technology development is largely privileged over other types of innovation; yearlong car development programs are strictly managed through the stage-gate model, which shows its influence across the entire organization.

Two overall categories of projects – those linked to research (that is, technology development) and those linked to the car programs – differ in processes and timeframe. New car programs typically start every second year and end with the release of a new car cluster. Through this process, many different groups work in parallel on different parts of the cars within their areas of specialty in the R&D organization. At the same time, these groups must work within a tight timeframe to stay in step with the general car market. As a result, there is limited space for new innovations to find their way into the car design after the car program has been initiated.

By contrast, the research projects have an explicit focus on exploring innovation potential. They often start as a pre-project effort within the individual departments and focus on developing new technological possibilities that could be used in the next car generation. At the end of the project, it is assessed whether the new technology is mature enough to enter into an upcoming car programs or whether it will have to wait another two years (or be shut down).

Most of the people in the UX center were employed within the software industry before coming to Volvo; they are used to development cycles of 3–6 months, rather than the yearlong timeframes at Volvo. Because the software market develops notoriously fast, an agile approach not only reduces time to market but also ensures relevance of the products released. But the UX center also focuses on innovating experiences rather than technologies, which might mean finding new ways of using or combining existing technologies into new solutions. With the new seed initiative that Sebastian proposes, the team seeks for to bring this agile, experience-based innovation into the organization.

But in order to make quick adaptations and flexibility possible within Volvo, significant infrastructures must be modified. Various elements and their historic manifestations take part in forming these infrastructures, such as the business models directing the company, the way budgets are structured, how decision paths run through the company, the physical distribution of departments, and external elements such as industry standards.

Sebastian's actions in this episode are an example of how the UX designers' common project of promoting UX manifests in efforts to revisit the taken-for-granted and make infrastructures more malleable.

Currently, a yearly sum of money is allocated to research projects based on the planned stages of the work and expected timeframe, amongst other things. But with its roots in an agile development understanding, the seed projects require a different structure. They will have to be financed from the same pool of money used for the research projects, but laying out a project plan once a year in preparation for budget allocations is more difficult; plans are likely to emerge from many different sources and ideas (such as user studies, new trends, new technological opportunities, and strategic wishes). The projects might potentially feed into on-going car programs, providing that these programs' structures are also made more agile and open to change.

So far, UX designers have been hampered in their performance because of limited budget allocations, unclear decision paths, difficulties in disseminating their input, and a lack of influence on early decisions, amongst other things. These circumstances are sedimented in the organization's infrastructural layers. Indeed, this texture of systems, procedures, agreements, templates, and management tools does not leave room for the full re-production of the bundles of practices that UX designers carry with them into Volvo. They confront structures in the organization that hold them back, force them to do things differently, and even frame their work as irrelevant.

By explicitly pushing, bending, and expanding the existing infrastructures, these designers aim to make more room for their doings among existing engineering design practices. The question is – how much room for change has actually been created and how much can be attributed to the UX designers' efforts?

Making Room

One may ask what relevance the efforts described in Episode 3 and 4 have for engineering work. We argue that what might seem to be organizational processes on the surface can in fact be understood in relation to an ongoing transformation and negotiation of engineering expertise. The prevailing engineering practices and professionalisms in Volvo are strongly linked to technology development and industrial production processes, as reflected in the current organizational structures, including stage-gate models and demarcated budgets for technology development. The UX center's approach to engineering design is instead linked to user engagement and iterative development cycles, which require different organizational frameworks in order to unfold productively. The negotiation of organizational structures hints at underlying negotiations of the engineering professionalism that has been taking place within Volvo recently. This negotiation will be relevant wherever a company management decides to bring in new ways of doing engineering.

The practice carriers act within and through existing infrastructural frameworks, but they may also intervene to add to or change the infrastructures. While this may sound simple, even mundane, it is far from a straightforward endeavor. As Star (1999:382) points out, *Because infrastructure is big, layered, and complex, and because it means different things locally, it is never changed from above. Changes take time and negotiation, and adjustment with other aspects of the systems are involved. Nobody is really in charge of infrastructure.*

Therefore, these infrastructures connect attempted changes in one part of the organizational constellation with the social orderings found in other parts. So while Star points out that infrastructure is never changed from the top down, it is also worth pointing out that it will not change from the bottom up, either. In fact, the notions of "top" and "bottom" become irrelevant (Schatzki, 2016). Instead, one might say that change needs to happen across the entire constellation, which includes management practices and everyday engineering design practices (and much more).

Because of such complex relationships running through a large organization like Volvo, the institutional infrastructures can create significant inertia in engineering design practices. Lasting change cannot be created within a single local scene of action on its own (such as within a single department); it has to happen more broadly. Change will typically come as reforms (gradual and moderate changes) rather than revolutions (drastic and wide-reaching change). In other words, change requires time, effort, and patience. And even then, agency may only take you so far – a window of opportunity for change needs to emerge in the ecologies of practices.

NEGOTIATIONS CONTINUE

In this chapter, we have so far attempted to show how engineering design practices rely not only on practice carriers to re-produce and maintain the practices through their actions, but also on room to unfold within the web of infrastructures embedded in any given situation. We have shown how making room for new or changing engineering design practices is a challenging endeavor for the practice carriers. The intricate relations between practices contribute to a certain stasis, which is sedimented into layers of infrastructure. These infrastructures allow room to be negotiated within the established ecologies of practices but only open up to new ones with great difficulty.

We were interested to know if the UX designers were in fact successful in their endeavors to create room for new forms of engineering design within the Volvo organization. About a year after the field visits were finished, the site was revisited to get an update from Sebastian on what had happened. Unsurprisingly, much had changed.

A reorganization of parts of the R&D organization, including the UX center's organizational relation to the other departments, had been announced six months earlier. The seed-project initiative that Sebastian worked on in Episode 4 was an effort to carve out part of the official budgets for UX activities and to mature these efforts so as to make them useful to other parts of the organization. These suggestions, however, were based on the organizational configuration of the UX center as a separate unit. Since the reorganization, this has changed. The UX designers are still geographically located in the UX center in Copenhagen, but organizationally they now fall under the management of three different Swedish leaders. One group is working with long-term strategy and conceptualization, another with early-system and product development, and the last with the industrialization phase. Each of these are now integrated with departments located in Gothenburg.

Looking at the new organizational integration of the UX center, we can argue that more room has indeed been made for UX engineering design practices, though whether it is enough room, or the type of room they were hoping for, is more doubtful. Nonetheless, the UX designers now have layers of infrastructure supporting their work and facilitating their interactions with other parts of the organization more clearly. Sebastian points out,

> *You can say that there's a different framework now. We are more integrated – that is, the processes also apply to us. The budget realities also apply to us, and so that balance between how much new we will develop over the next four years, how much maintenance, and how far out in the future we are allowed to look – well, the same rules apply to us as for the equivalent people in Gothenburg. So, in that way we are more integrated and we have less autonomy, but I also believe we'll make a larger imprint on people's user experience in a Volvo in five, seven, ten years in the new setup than we could have done in the old.*

How was this achieved? Though the answer is complex, there are indications that outside circumstances, as well as the UX designers' local interactions, have influenced this change. As Episode 3 suggested, it was already apparent that an official organizational change was needed to accommodate changing conditions in the different departments. In the meantime, efforts had focused on completing the release of the latest car program. After this had been completed, management rolled out a larger reorganization of the electronics R&D organization (of which the UX center is a part). Sebastian explains it like this:

> *It [the reorganization] basically comes from the management of this […] R&D organization [the electronics part]. At this point we have just launched our new flagship – the XC90 is out on the streets – and so now is a good time to say 'It's here now and now we can afford to look a bit further ahead' and make some of the adjustments that are necessary in order to work more efficiently in the long term and cover some of the holes or weaknesses of the old organization.*

In other words, a window of opportunity had opened for organizational change, which was both necessary and possible after the launch. While the UX designers had been pushing for a change (for example, through the seed project initiative), this local effort did not cause the change single-handedly. The team's efforts had to fall in step with other local efforts in the organization and create a momentum significant enough to break with the existing structures and start forging new ones.

Bringing the UX designers into the organization in 2012 was an investment and a strategic move for the management. But although the UX designers have worked hard to prove their worth, their impact remained moderate over the first three years – something that would not have escaped the attention of the management. *I also think that the vice-president wanted a greater impact from Copenhagen [the UX center],* Sebastian said, *and he saw that, well, you need to be more integrated in order to balance 'it has to be visionary, it has to be good for the users' but 'it also has to be doable and it has to end up in the products' – that balance is more easily obtained when you are a part of the machine rather than on the outside. And I think that's correctly spotted.*

At the same time, Episode 2 gave an example of how UX designers had worked for some time to build local relations with people in other departments. Continuing the work with the seed project (subsequently renamed Advanced Experience projects, or AEX), these efforts continued more or less openly. One of these projects, for example, included not only the UX center but also the IT department, the Product Planning department, and customer service.

Like a ripple effect, in which one interaction led to many others, UX practices were already starting to influence and be influenced by the bundles of practices rooted in other parts of the organization, thereby creating the momentum for change. New types of collaboration started to blossom, yet lacked any structural support. The local scenes of activity within the organization were already shifting, creating tensions across established organizational infrastructures. Therefore, while the resulting change may not have been what local practice carriers had hoped for, it was an attempt to release some of the built-up tensions by affording room for new interactions.

Sebastian appears to be quite optimistic about this development. He says, "Earlier it was that agenda, à la, 'We'll show them! There's a new way of doing things.' And also that discussion we had all the time concerning 'Let's do it our way and set a new standard' versus, 'Why is it such a big problem for us to fill out the normal project templates? What is it we cannot describe?' – we don't have that anymore; there are some things that are given. But in return the management of the new development organization also says, 'We want a change of this organization. We need to work in a different way. And we need your input to move forward.'"

Therefore, while the UX designers have had to sacrifice some of their autonomy and idealism, they have also gained a new influence on the collective work of the organization.

Making room for user-oriented engineering design practices appears to be an ongoing endeavor, one which weaves together with the everyday practices of engineering design. This stasis is reproduced and supported through the multifaceted texture of interconnected practices, material arrangements, and institutional infrastructures. Change is rarely the achievement of the individual – in fact, it is dependent on openings in the larger ecologies of practices, rendering new constellations viable and allowing for new infrastructural layers.

CONCLUSION – THE IMPORTANCE OF MAKING ROOM

While engineering as a whole is a relatively young profession, historically speaking, it is nevertheless a profession with a significant tradition and staunch identity. Civil and mechanical engineers remain sturdy pillars of the engineering community, but they are also increasingly being joined by new engineering colleagues with somewhat different takes on what 'real engineering' is (or perhaps, rather, how widely engineering can/should grasp as a profession). One of these new approaches to engineering is the user-oriented approach to engineering design, which (in the version discussed here) focuses on holistic and socio-technical dimensions. The overall aim is the same (developing successful technological solutions), but the way successful is understood differs (useful rather than functional), as does the means of reaching it (based on user needs rather than technological requirements).

The episodes presented here have illustrated concrete efforts to challenge what counts as 'real engineering', or what is recognized as part of engineering expertise. That is, an attempt to transform engineering professionalism leaves room for a more holistic approach to technology development and to the social factors of technology use.

Our point is not that one way of doing engineering is better or "more right" than another. Rather, engineering (or the products engineers develop) can be changed neither from the top nor the bottom. This case shows us that merely bringing in new engineers with new competencies or forming a new department with an alternative focus will not change much (cf. Buch, 2016). Engineering practices do not exist in isolation within an organization, and a transformation therefore requires a change in the very ecologies of practices that exist across an organization.

Alternative perspectives also mean alternative ways of approaching a task and evaluating the successful of the result. To a great extent, organizational structures, running across departments and management layers, frame what is possible in the everyday life of a workplace.

Universities invest great effort into developing new types of engineering profiles, or simply updating the traditional ones to better equip the coming generations of engineers to tackle future challenges. It is, however, important to recognize that such efforts alone will not ensure a renewal of engineering practices that we find across workplaces. A shift in focus from individuals to practice ecologies can help us see the challenges of introducing new practices into existing organizations. Structures and normativities run deep within an organization and may only be challenged through a joint effort reaching beyond the individual practice carrier and even beyond distinct professions. Opening up negotiation of how we do things, or what we count as success is a daunting endeavor, but a necessary one in order to make room for user-oriented approaches and other new types of engineering design professionalisms.

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10. USER REPRESENTATIONS IN DESIGN WORK IN A MEDICAL DEVICE COMPANY

INTRODUCTION

In this chapter, our analytical scope is to understand the relations, tensions and dynamics surrounding the multiple bundles of practices related to user representation in the design work in a medical device company. Based on observations of four 'situations' that evolved around user representation in the company's product line, we argue that these practices are shaped and reshaped by different meanings, competences and materiality (Shove et al., 2012). While educational background plays an important role in configuring engineers' and designers' work practices, the innovativeness of traditionally organized companies shapes and reshapes user representation practices in design work. The first three 'situations' relate to the practices of a Design and Innovation engineer employed as an 'user expert' whose main work function was to perform user tests. To broaden the discussion of user representation in design work, the fourth 'situation' illustrates the practices of an industrial designer who was assigned a specific task to develop a colour for one of the company's products. Each situation is elaborated with a discussion of practices associated with the described situation.

When discussing 'design', scholars and laymen alike tend to do so from a very situated point of view, most often without recognizing that their own perceptions of design may not correspond well with those of others. A review of the literature makes it apparent that design is introduced and defined in a variety of ways. Simon (1996) argued for a broad everyday practice interpretation, Cross (2000) argued that design is the creation, development and documentation of products, whereas Lawson and Dorst (2009) defined design as the practice of professional designers. Common among these definitions is that design is shaped around creating a physical artefact; in other words, designers 'make things'. This view seems to remain dominant, Kimbell (2011:290) argued, because when entering a design studio, *you are likely to note a disorderly arrangement of objects on work surfaces, walls and floors*.

Professionals who engage in design are engaged in careers as diverse as fashion design, industrial design, architecture, software design and engineering. Even though all of these professionals use the word 'design' to describe their work, their practices are significantly different. Thus, to capture and unfold the practices of user representation in design work, we study the design practices employed by two

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different types of professionals in a medical device company: general engineers and engineers with specific educational backgrounds (e.g., design and innovation engineers, and industrial designers).

Our examination of this topic is based on a multi-sited ethnographic study performed over a period of 2 years (2011–2012) in a medical device company in Denmark. The focus for the study was to understand: (a) the practices employed in the company's design work, (b) what comprises design work, (c) the company's definition of 'user involvement', and (d) how users of the medical devices are involved (or not) in the design work.

User involvement in product development has a long history. As far back as the 1950s, designers began to recognize the potential of understanding the needs of the users of their products. What has become known as 'user-centred design' evolved during this period. In user-centred design, the 'user' is seen as a subject of study and is observed and analysed at a distance; these distant observations are represented in the design work. During the decades that followed, designers gradually moved closer to the subject (the user), who in the 1970s was 'allowed' to participate in design processes; thus, the approach known as 'participatory design' evolved. This approach meant that the designers started asking users questions and involving them in testing out prototypes created by the designers. The role of the user was to inform experienced designers who then created new designs. Since the 1970s, the participatory design approach has evolved to become even more 'participatory' beyond merely asking users questions or having them test prototypes. However, it was not until the notion of 'co-design' was developed in the 2000s as a further development of participatory design that the role of the users changed from 'informants' to 'co-designers'. Co-design takes the final step towards users—from observing users (user-centred design), to engaging users (participatory design), to collaborating with users (co-design) (Steen et al., 2007; Sanders & Stappers, 2008; Jørgensen et al., 2011a). Given this history of the evolution of design practices, we asked: Which practices of user involvement are employed in the various design practices of the medical device company?

As we studied the practices of the user expert team, it became apparent that although two of the engineers' educational backgrounds emphasised co-design, it was very difficult to change others' existing practices related to user representation. Thus, in this chapter we discuss how practices related to user representation are shaped by the actions and dialogue of current, previous and potential practitioners that reveal what they see as 'meaningful', and which 'materials' and different 'skills/competences' the engineers and designers use in their routinized work as they strive to represent users. This discussion also includes how engineers and designers translate requirements, procedures and outcomes as they attempt to navigate evolving tensions around user representation.

Empirically, our discussions are based on four observed 'situations', meaning that the 'situation' is the focus of our analysis (Clarke, 2005). By studying the different meanings (ideas, aspirations, symbolic meanings), competences (know-how, techniques, skills) and materials (things, objects and tangible physical entities) we can obtain an understanding of local practices (Shove et al., 2012:10–14). Thus we view practices as *routines bodily activities made possible by the active contribution of an array of material resources* (Nicolini, 2012:4). According to Shove and Nicolini, practice cannot be reduced to only meanings, or only competences or only materiality. Rather, it is the conceptualization of people and things as the 'carriers' of practice (and of many different practices that are not necessarily coordinated with one another) and therefore the carriers of certain routinized ways of doing, understanding, and knowing (Shove & Pantzar, 2005).

In practice theory, objects are necessary components of a practice: *Carrying out a practice very often means using particular things in a certain way* (Reckwitz, 2002:252). Shove and Pantzar (2005) argued that new practices consist of new configurations of existing elements or of new elements with those that already exist, and what really matters is how constituent elements fit together. But practices also require continual reproduction. People must employ practices, and investigating who, when, where and how this occurs is important. In this sense, practices are inherently dynamic. Practitioners are the 'carriers' of the practice and make the practice happen.

We obtained the empirical material for this chapter by performing ethnographic interviews, making observations, creating thick descriptions, participating in meetings, reading documents and following the actors throughout a 2-year period (2011–2012) as we studied the company.

APPROACHING THE FIELD

The company we studied is situated within the medical device sector. The company is organized as a traditional manufacturing company, with sharp distinctions between the work of designers, engineers and marketers, as well as between the functions of 'front-end innovation', product development and marketing. Figure 1 depicts the company's organizational structure.

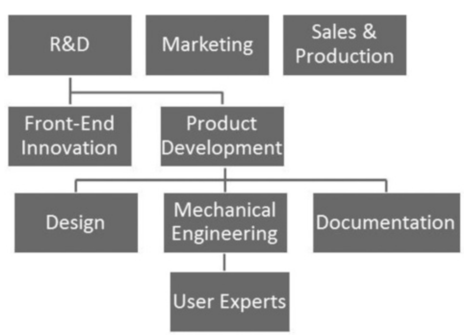

Figure 1. The organization of departments and units in the company

The company promotes itself as closely collaborating with users and having a specific focus on user needs. A brochure published in 2008 included the company motto: *'Listen and respond'* (Kragh, 2008:5). Upon closer examination, it become apparent that this motto and focus on users and user involvement seemed to pertain mainly to 'front-end innovation', not the entire product development process.

The company was established in 1954 by a nurse whose sister had to have an ostomy due to colon cancer. At age 32, the founder's sister had to change her entire lifestyle to accommodate the ostomy. No medical devices were on the market to support this radical change, and her sister was faced with constant fear of leakage and odour. In an attempt to help her sister, the founder began experimenting with the newly invented plastic bag. She succeeded in producing simple prototypes and later she managed to persuade a manufacturer to mass-produce them. Thus, the foundation of the company was laid. The history of the company shows that its user-centred design strategy can be traced back to the founder. Elgaard Jensen (2013) argued that three modes of user involvement are at play within the company: *sisterly empathy* where the focus is on observing, listening and responding to users' needs, *clientele building* which is based on a strategy of maintaining lifelong relationships with ostomy nurses and patients to ensure mutual dependency, and *turning users into a source for radical innovation* in which designers draw on users' ideas and experiences to innovate new products. This third mode is mainly observed in the company's 'front-end innovation' activities.

The study that forms the basis for this chapter relates to the mode termed 'clientele building', which is the company strategy that is dominant within the product development department. Empirically, we studied design practices in the company from the perspectives of different developers. Our interpretation of the word 'design' and what design practices encompass processes from front-end innovation to product development. We began by studying the mechanical design department, and moved to documentation, product development and front-end innovation. The focus in this chapter is on user representation practices in the design work of the product development department

Table 1. An overview of how users are represented in different departments of the company

How users are represented in the different departments in the company	
Marketing department	Market needs assessments: users are seen as customers Quantitative data: users are represented as numbers
Front-end innovation department	Observations of objects Experiments with objects (mock-ups) in lab facilities. Test of mock-ups with end-users
Mechanical design department	Test of prototypes: usability tests

The table illustrates how users are represented in the different departments in the company. We return to the table and a discussion of user representation later in the chapter.

PRACTICES RELATED TO USER REPRESENTATION IN DESIGN WORK

In this section, we unfold the observations of one of the researchers during the ethnographic field study. The field study was carried out using an observer-as-participant approach. Adler and Adler (1994) described the role of observer-as-participant as observing subjects for a brief period of time while conducting structured interviews. The strength of this approach is that it is possible for the researcher to build close relationships with the persons observed. We use personal pronouns to reflect these close relationships as we describe the practices of a design and innovation engineer employed as a 'user expert' whose main work function was to carry out user tests, and an industrial designer who was assigned a specific task of developing a colour for one of the company's products.

It was a Wednesday evening in December, and Rie, a design engineer working as user expert, and I were visiting an ostomy user, Ole. Rie was to perform a user test for a prototype of a closing mechanism for a new ostomy bag, and I had been following her over a couple of months to observe how she conducts, analyses and communicates the insights from these user tests to members of other departments within the company. Rie was part of a 'user expert' team of three engineers, comprised of two design engineers and one person with an educational background in plastic engineering. The user expert team's purpose was to carry out user tests of products under development, to observe end-user practices in relation to the company's products, and to report back to the marketing department and the different development teams. Ann, the other user expert with a background as a design engineer described their role and relationship to the marketing department:

> *It is very much controlled by marketing…marketing [team members] do the initial research, exploring needs. For example, they discovered that 50% of users experience leakage…. They [marketing] then develop some initial guidelines, like a more broad needs assessment. Based on this, we define what this need means in practice and how it is related to the products.*

Two days before the visit, Rie and I sat at her desk in front of her computer, and she explained how she prepares for user tests. Her desk was located in a large office shared with the other user experts and two other development teams. The atmosphere was hectic, but cosy. People were coming and going, discussing issues across desks or talking on mobile phones. Several times while we sat and talked about how she prepares for user tests, colleagues interrupted her with questions of all sorts. It was clear that she was the one her colleagues went to with questions about the ongoing user tests.

Situation 1: Preparing User Tests

While sitting in front of her computer, Rie explained that the aim of the user tests were to create final documentation of the product's usability. Prior to these tests, the closing mechanism, the material of the bags and the filters had been tested several times. Now, it was time for final testing of the prototype. Specifically, they were testing whether users were able to connect the closing mechanism.

> *It's pretty much what we are expected to bring back from the tests. Of course it is nice to gain details on whether they find this easier than other products. But what we need to gain information about is whether the user is able to make the closure by reading an instruction, or if oral guidance is needed*.

Rie explained that she was not going to perform all of the tests personally; this task had been divided among the project team members. To ensure consistency, the marketing department had specified the types of information to be gathered in a spreadsheet that was to be filled out during the test. She explained that she and her colleagues on the user expert team felt that the information to be collected was too narrow: for example, the team members were to rate the user's ability to close the mechanism on a scale from 1 to 4, where 1 is easy and 4 is difficult.

The user expert team questioned what could be learned from these ratings, so they negotiated with the marketing department to video record each user test so the user experts could analyse the situations afterwards. Rie elaborated that since the project members (mainly engineers from more traditional disciplines such as mechanical engineering, chemical engineering, etc.) were not trained user experts, she and her colleagues had developed a template to provide the project members with information about the users who would be visited. This template contained information about which products the user already used and whether he or she had participated in other tests. She had explained to the project team members that it was very important that the users had positive experiences during the tests, since they were to be involved in tests of other products in the future. '*Creating a good atmosphere'*, Rie explained, meant listening to the user, even about issues unrelated to the test. This entailed, for example, sitting down and having a cup of coffee with the user if it was offered, since such activities contribute to creating a positive user test experience.

When preparing for the user tests, and also later when analysing the results, a tension between two practices emerged: a practice in which quantitative data (the rating of the user's ability to use the device from 1 to 4, where 1 is easy and 4 is difficult) conflicted with more qualitative data practices. Given their backgrounds as design engineers, the user experts struggled to translate user experiences into numbers without being able to represent users as 'people'. This also highlights the issue of what is *meaningful* and what contributes to making one's work meaningful. For the user experts, it was not meaningful to translate their insights into a rating system, thus they sought to translate their insights using quotes, as depicted in the next situation. Further, the user experts knew it was difficult to ensure inter-rater reliability among several team members. To address these problems, they proposed the idea of video recording the user tests. Through this materiality, the user experts would be able to analyse the tests personally and assign ratings—a process they felt skilled to carry out.

This and the following situations highlight the role of educational background in work practices; thus, we provide a short description of the user experts' educational backgrounds.

The User Expert Team

The two design engineers on the user expert team had master's degrees in design and innovation engineering from the Technical University of Denmark. This program was established in 2002 and breaks with more traditional engineering education programs, since the basic knowledge and skills components emphasise 'innovative, socio-technical competences' and 'creative, synthesis oriented competences' on equal terms with natural science-based competences (i.e., the more traditional engineering competences). The aim of the program is to train holistic engineers, and an important part of the curriculum focuses on providing students with analytical tools and including users in setting design criteria and defining the design specifications (Jørgensen et al., 2011b). Beth, the third member of the user expert team, had a formal education as a plastics engineer. She had involved users in product development for over 30 years. Traditionally, this type of engineering education (plastics engineering and mechanical engineering) emphasises quantitative methods in line with what the marketing department requires. Beth, however, distanced herself from this quantitative and systematic way of approaching user needs and argued that product development is about following one's own gut feeling:

> *There is a tendency—also here in this company—to approach product development very systematically. But I know, we who are out there with the users, we know that it is very much about one's own gut feeling. Our job is then to get feedback on these gut feelings…I don't think you can systematize gut feelings…I trust my gut feeling and not the systematic approach I am supposed to follow. Of course there are elements that I need to follow, like leakages must be avoided. But in relation to people's comfort and their feeling of safety, then I trust my gut feeling.*

Beth described competences from her practice as a user expert and she trusted the information provided by users, whom she viewed as competent persons. Beth suggested an approach to product development based more on know-how rather than the quantitative and systematic approach used by the marketing department.

Within the user expert team, there is a practice around users and user involvement that goes beyond viewing users as mere numbers that can be quantified and uniformly analysed. This practice is reflected in how the user experts try to navigate within the frames set up by the marketing department. For example, by persuading the marketing department that all user tests should be video recorded, the user expert team was able to engage in further analysis after the completion of testing. In the marketing department, the more quantitative practice of ratings seems to stem from the idea that numbers are easily translated into product satisfaction or dissatisfaction that again can be transformed into design input/output criteria. According to Rie, this idea of numbers being easily translated into product satisfaction or dissatisfaction may originate from the educational backgrounds of the marketing department staff members. In the marketing department, all staff members had business degrees in international marketing management, economics and marketing, finance and strategic management, or strategy and innovation. Beth questioned this tendency toward quantification: *'We are in a world of documentation and it is getting worse and worse. I think we need to be very careful that this is not getting too nerdy and too inflexible. We need to consider how to document gut feelings and less on how many users say what.'*

The user expert team seemed well aligned in their visions and how they approached their work as user experts. Ann expressed: *'We act as what they call a competence centre. When we are allocated to projects, then it is the whole competence centre and not only one of us. We are very pleased with this, since in this way we can use each other's competences.'* This raised a new issue in relation to understanding the premises of the user expert team and their professional practices. For each product under development, a project team was allocated a certain number of hours to be spent. This also applied to the user expert team. Thus, they allocated between 10% and 50% of their time to a specific project with the aim of performing user tests. Ann explained:

> *There is a rather large demand on our competences, but it all falls back on resources. The executives and project managers run resource workshops among themselves (where it is decided how much time each unit is allocated to the project). I think we sometimes need to fight to get them to recognize that users are important.*

Based on this discussion, it seems as though strong alignment among the user experts contributed to the meaningfulness of their jobs and practices in representing users.

TRANSLATING USERS' KNOWLEDGE INTO MORE THAN NUMBERS

As discussed in situation 1, the user expert team questioned the information gathered from ratings, since the ratings would be assigned by the individual team members and thus be subject to several interpretations. By video recording the user tests, the user experts would be able to both analyse the user tests personally and put themselves in a position to assign the final ratings, thus ensuring some consistency in the final 'numbers'.

The preparation practices for the user tests also reveal how the user experts tried to influence the design process and make the user visible to product development team members. By developing a template (an object) with user information for each individual user who would be performing the user test, the user expert team drew attention to users' backgrounds, which products they used, and which tests they had performed previously. They argued that in order to make users feel comfortable, the project team needed to show that they understood their lives and daily practices.

In the home of the ostomy user, Ole, Rie and I sat in the kitchen drinking coffee. It was close to Christmas, and the house was decorated for the holiday. Ole seemed relaxed and happy to be talking to us. Prior to the visit, Rie had asked me if I could video record the test. If I had not participated in the visit, Rie would have had to do the video recording while explaining the test, observing the test and assigning the ranking on the spreadsheet provided by the marketing department. I, of course, agreed to do so because she told me that ideally it takes two people to perform the test, but normally this is not possible, since they have too many tests to perform in a very short period. She further explained that during her education, a minimum of two people participated in performing user interventions. This highlights a practice among design and innovation engineers that user interventions are performed by teams, not by a single individual.

Situation 2: The User Test

Rie began by introducing herself, explaining her role in the company and the purpose for her visit. She explained that I was there to observe and that I would be video recording the testing process. We sat down at the kitchen table, and Rie

Picture 1. The user explains his initial reaction to the prototype.
(Picture: Søsser Brodersen)

placed 4 ostomy bags on the table. Ole was very talkative, and quickly an informal conversation evolved about the products he used both currently and in the past. After 10 minutes of informal talk, Rie selected one of the ostomy bags and asked Ole what he thought about the bag in terms of the colour and material.

Ole explained that colour was not important to him. The old bags he used were colourless, and he did not mind that. Rie then selected the closing mechanism and explained that it was a prototype of the new product. She told Ole that she had tested how it felt to wear it for a day, even while doing fitness activities. Rie then placed the instruction sheet on the table and asked Ole to read the instructions on how to use the closing mechanism, and then test whether or not he could do it himself based on the instructions.

Picture 2. The user reads the instructions prior to the test.
(Picture: Søsser Brodersen)

Rie asked if he normally read instructions, and Ole replied: *'I am a craftsman.'* He elaborated that this meant no. After Ole read the instructions, we all moved into the bathroom to do the test.

In the bathroom, Ole removed the old ostomy bag, cleaned the skin and placed the new filter. He then clicked on the new bag, and asked if that was all. He added that he did not feel anything different in the closing mechanism than the one he already uses. However, he did mention that he felt a bit unsure of whether the closing mechanism was secure: *It feels like it may drop off*.

While Ole tested the closing mechanism several times and I video recorded these processes, Rie asked Ole how the closing mechanism felt and if he felt secure that it was closed. Ole then compared the closing mechanism with those on the bags he already used to give her an idea of the usability of the closing mechanism. Not until the test was finished and Ole put on his normal ostomy bag did Rie assign the rating on the spreadsheet. On our way back from the visit I asked her if this was her normal practice, to not assign the rating while doing the test. Rie confirmed that this was her normal practice because a rating could easily be assigned after the test

Picture 3. The user tests the prototype.
(Picture: Søsser Brodersen)

since it had been video recorded. She said it was more important to be in the moment with the user and not 'absent' due to having to fill out the spreadsheet. If she had doubts later on, she could always watch the video again.

This situation reveals that it was important for Rie to show that she had empathy and was willing to understand what it is like to be a user of the product. For instance, she mentioned that she wore it for an entire day, including during fitness activities. This indicates that the user experts had the competences to put themselves in the user's position and that they know this was important to building relationships in user testing situations. Before the actual test was performed in the bathroom, she introduced an instruction sheet explaining how to use the product; thus, an object was introduced to Ole with a mediating purpose. At first Ole rejected the object, explaining that he never reads instructions. The user expert explained that it was important for the test results that he read them and judge whether they were understandable or not. By creating an informal and cosy atmosphere, she managed to enrol Ole in the testing process, even though it required him to read the instructions. Again the user expert showed that she had the competences and know-how to create the right atmosphere for the user test.

The situation also reveals that the user expert had a practice of being in the moment and not being occupied with filling in the spreadsheet. Thus, Rie did not allow the spreadsheet to influence her interaction with Ole. Again this practice can be traced back to her education, where 'observation' as a methodology played an important role in learning how to intervene with users.

Situation 3: Analysing the User Test

A week later, I met Rie again. Most of the user tests had been carried out and she was in the process of analysing the test results and organising them so they could be handed over to the marketing department. Again, we sat in front of her computer in the shared office. On Rie's computer screen, I saw a bar chart created in PowerPoint. On the right side of the page, I saw several quotes related to safety. Rie explained that the bar chart represented the quantitative information required by the marketing department: the ratings from 1 to 4 related to the usability of the closing mechanism. The quotes were Rie's idea. She eagerly explained:

> *The bar charts are what marketing wants. But I think we need to include some comments, especially comments related to safety. We cannot just state safety without reflecting on what safety means…If it was up to marketing, then they would be satisfied with knowing how many stated what. But I feel I need to understand the users, like 'Who are they?' and 'Which products do they normally use?' I think we need to know this, otherwise we cannot understand the rating*.

Rie explained that what made the user expert team unique was that they had the competences to understand that 'easy to wear' does not mean the same thing for all users. And 'easy' cannot just be rated 1, which the marketing department had a tendency to do. I asked how the ratings were assigned, and she explained that they were based on her judgment. She recognized that this judgment put a lot of responsibility on her shoulders. Since the rating relied on her judgment, she felt most comfortable reviewing all of the videos recorded by team members to make sure their ratings reflected what the users expressed during the tests. She explained, *'I need to listen to what the users say'* before adding the number into the bar chart.

The product that was tested was a prototype of a product that the company had already decided to manufacture. Nevertheless, Rie deliberately chose to include the quotes with the bar chart. She explained that her motive was strategic in that she was trying to push for a more holistic, user-centric approach in the marketing department. But Rie also had a personal interest in 'safety' and exploring what 'safety' means. She explained, '*I am also very interested in safety and to be involved in projects focusing on safety, like what makes a person feel safe, like is it routines, habits, etc.*'

This situation raises several issues. One issue is related to the translation of user information. The marketing department required the user experts to translate user insights into numbers ranging from 1 to 4, since these numbers are easy to translate into design input/output requirements. A user expert translated the ratings into people again by adding quotes to the bar chart. This action was central in several ways. It was a strategic move made by the user expert, since she wanted to influence the marketing department to take a more holistic approach towards users. It also reflects a practice that recognises that different actors have different interpretations of safety. As a user expert, Rie interpreted safety as including an understanding of the users and the products they use, whereas members of the marketing department interpreted safety as a number between 1 and 4. Thus, incorporating quotations transformed the framing of the user test from a simple materiality into a more complex materiality, allowing for interpretative flexibilities of, for example, the meaning of 'safety'. The need to open up the black box of safety reflects a practice of the user expert that is directly linked to her educational practices. As she studied to become a design and innovation engineer, she worked on projects related to safety and the importance of understanding different meanings when designing products or systems where safety is at stake. For the user experts, quotations became a very important materiality that enabled them to communicate their user knowledge and thus help others understand the ratings.

Another issue raised in this situation was that in order to ensure the users were represented correctly in the ratings, the user expert examined all of the videos of the user tests, including those performed by other team members. Her argument was that since the ratings were highly important to the marketing department, she wanted to be sure the ratings were based on equivalent judgments.

The Visibility of Voices: The Wall

When entering the shared office in which the user experts worked, one of the most noticeable features was a huge whiteboard with pictures and short stories about a variety of the company's users. On this 'wall' the short stories were supplemented with statistics in the form of bar and pie charts indicating usability test results for some of the company's products. Rie explained that this wall had been developed by the user expert team as a materiality to represent the end-users as more than numbers and statistics. They wanted to give the users a voice and make them visible and present for the project teams. When I asked about the 'wall', Rie explained,

Figure 2. The 'wall' serves as a materiality to represent users as more than numbers. (Drawing: Signe Pedersen – Confidentiality prohibited us from taking a photo)

These are people—they are not just numbers. Thus, the user expert team translated the users from being numbers into being people again, and used this wall to mediate between the users of the ostomy bags and the engineers in the R&D department as well as the members of the marketing department.

As shown in Table 1, users were represented in different ways in different departments in the company and the user experts 'sold' their insights about users to the rest of the company. This reflects a very traditional distribution of work: the marketing department was responsible for exploring potential markets and products, the engineers developed the products, and the user experts performed user tests. In addition, the company had a design department comprised primarily of industrial designers. Recently, the company had made some organizational changes that realigned the design department with the R&D department in the corporate hierarchy. Managers decided to create a separate design department in order to implement a 'design DNA' strategy in the product line. We followed one of the industrial designers, Jay, before and during this reorganization, because we wanted to understand how users were represented in the designers' practices.

When we first met Jay, he was working on the colour and material of an ostomy bag. While walking through one of the design labs in the company, Jay explained that the marketing department had assigned him the task of developing the grey colour of an ostomy bag to ensure the invisibility of faeces when the ostomy user was dressed in a white shirt.

Situation 4: Test in Design Lab: Users Represented by Models of Skin Colour

It was a Wednesday morning and Jay and I were on our way to the design lab. Jay explained that the company did not have standard test models to experiment with colours, so he had developed his own experiment. Once we reached the design lab and were standing in front of the experiment, Jay explained that through some basic internet research, he had identified four characteristic skin colours: North European, Asian, Arabic and African. Based on these characteristics he created coloured materials that approximated the characteristics of skin and began to test different shades of grey (warm, cool and neutral).

Jay continued by explaining that after he had done the test on the four skin colours, the marketing department decided that the main markets for this specific product were countries in which the North European colour is dominant. Jay then focused his lab tests on this specific skin colour. The results of the lab test, Jay explained, were that the warm and cool shades of grey caused urine to look dirty, whereas the neutral grey rendered the urine invisible.

This situation reflects a practice of representing the users without their direct involvement. Through an internet study, the industrial designer identified that users generally have one of four different skin colours. Based on this information, he built his own model to perform lab tests. The decision of which skin colour and which shade of grey on which to base the production of ostomy bags was based on this lab test. What may appear strange is that the decision about the colour of the ostomy bag did not involve any kind of active user involvement, especially when the company's mission and vision are linked to empathy, respect and listening to their users (see Figure 3).

Figure 3. The company mission

The industrial designer faced a dilemma over not involving users directly when determining colours, shapes, etc.:

> *When you design something, you need to know the user and this is a very time consuming process, despite how important it is. And often, time is not allocated for this. It is really a challenge that I have not had time to do user visits. So I have been forced to rely on the input I get from our user experts…and from marketing, who also knows the users. And when I start the actual design work, then the design DNA is a huge help, since it means issues related to shapes and expression are decided. I can then concentrate on how to handle the product and how to make it cheaper to produce.*

The industrial designer's practices of representing users by building a lab model of various skin colours to test the grey colour of the ostomy bags or relying on the user experts and marketers were challenging for him. Nevertheless, he seemed to accept that he contributes to product development primarily by shaping the materials. As an industrial designer, his educational practices appear to have involved users very little: the Kolding Design School (Kolding Design Skole, 2014) promotes its program by stating that industrial designers are competent and very skilled at playing with colours and shapes and generating ideas. Reading through the curriculum, it appears that the program has minimal focus on user interventions, which is a primary focus in design and innovation engineering education programs. We never discussed his educational background with him or how these practices influenced his current work practices. However, the emphasis on playing with colours, shapes and ideas in the industrial design curriculum may explain why he represented 'end users' using lab-created skin colours identified through internet research.

DISCUSSION AND CONCLUSION

This study of how users are represented in different ways in design work raises several issues that we believe merit further attention: the innovativeness of traditionally organized companies, how educational practices contribute to tensions between different work practices, and the intervention of new objects to represent users.

The Innovativeness of Traditionally Organized Companies

The studied company was organized in such a way that the user experts 'sold' their insights about users to other departments within the company. It is also worth noting that the marketing and R&D departments were interested in only a very small fraction of the user insights developed by the user experts. The company had a very traditional distribution of work: the marketing department was responsible for exploring potential markets and products, the industrial designers generated product ideas (colour, shape, etc.), the engineers developed functional products, and the user experts carried out user tests. The marketing department controlled the process of defining needs, as explicitly expressed by one of the marketing coordinators in the company:

> *[We] roll out the guidelines; we receive input from our countries, our users and explore the market, like what do the competitors produce and what do we lack to optimize our portfolio…We need to make sure that the product is useable for the market.*

The dilemma associated with this very sharp distinction was raised by one of the user experts as being symptomatic of a larger issue related to user involvement in the company: specifically, the marketing department having sole responsibility for defining market and user needs, and the engineers having sole responsibility for developing solutions. The user expert explained that in contrast to a holistic approach based on dialogue with users throughout different phases of product development, product development and user involvement were operating as separate entities. One of the user experts explained:

> *I think it is easy to see differences between us and those ordinary engineers, or whatever you call them. They approach [product development] by rushing into developing different solutions, without having defined the need we are seeking to solve with the product. This means that we end up with two parallel tracks.*

This means that end-users were not involved before the testing or adjustment phases. Further, in these tests, only functionalities were tested, not ideas, shapes or meanings of products. This user involvement practice seems to be in contrast with the company's desire to maintain close collaboration with ostomy users, at least if 'ostomy users' are defined as 'end-users'. The issue of who are the 'users' in the company was discussed by Elgaard Jensen (2013), who argued that in what he termed the *client building mode*, users are the ostomy nurses as much as the end-users. Elgaard Jensen (2013) also argued for a third mode of *turning users into a source for radical innovation*. One would have expected this strategic mode to be reflected in product development processes, but as our study has highlighted, user insights only seemed to be represented in the testing of prototypes. Our study further shows that even though a company sets out strategic goals of being innovative and attempting to interact with users in new ways, defining these goals may not be enough if the company is not organized to accommodate these goals (Clausen et al., 2012).

How Educational Practices Contribute to Tensions between Different Work Practices

Two of the user experts we followed in this study had educational backgrounds that emphasised 'user driven innovation'. They both highlighted how they had been trained as holistic engineers and the challenge this presented in their current roles as user experts. One of them explained: *We do not develop products as we were taught; I think we need to prioritise the initial research more.* The other user expert continued: *'We do not develop requirements and specifications until after the product is developed. It is not used to guide the design work.'* This seems to point towards a tension that emerges when an educational background as a holistic design engineer clashes with the design practices in a traditional product manufacturing company with a very clear distribution of work defined by different disciplines such as mechanical engineering, marketing, industrial design, etc. The two user experts with educational backgrounds as design and innovation engineers expressed this tension:

> *It is very much divided. I think we lose a lot of important information with this division. I think some of the motivation is lost when you just have to deliver input. I really want to be part of developing the product and not only providing information from the users.*

This study reveals how one practice is shaped and influenced by other practices. For example, Rie's educational background influenced how she translated users from numbers back into people using videos and quotes—methods taught and practiced during her project-based training to become a design engineer.

Comparing the design practices of Rie, the design engineer and user expert, with those of Jay, the industrial designer, it becomes evident that they approach and attribute different meanings to the designed object. Jay, in his experiment with the ostomy bags and his involvement in front-end innovation focused on colour and shape, whereas Rie and engineers often focused more on product functionality related to the use practice.

Intervention of New Objects to Represent Users

This study also shows that qualitative information from users such as Ole did not seem to play a particularly important role in product development practices. The user experts perceived this as a critical problem, since important information about the user is lost when insights are translated into numbers and bar charts, which results in user insights failing to be embedded into product development practices. To navigate within this practice, the user experts invented new ways of representing users in a meaningful way, for example, by creating the wall and by adding quotes to the bar charts and ratings when presenting their user insights to the marketing department. By visualizing the users' everyday practices on the wall, the user experts materialized their holistic design engineering practices combining 'meaning, competences and materials'.

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11. JAKOB AND THE MANIPULATOR

Engineers, Actants and Engineering Work

INTRODUCTION

Engineers work with technologies, they create them, they operate them, and in many ways such technologies define engineering. But how do engineers relate to the technologies that define their trade, occupation, or profession? How do they perceive, understand and envision the possibilities that their skills and competences equip them with when confronted with yet another technological project.

Through actor-network theories (ANT), the concept of 'actant' has been introduced to conceptualise non-human, as well as human, actors in technological networks. With a point of departure in a story about Jakob and the manipulator I investigate the relationship between the engineer, in this case Jakob, and his creation, in this case the manipulator (see picture on following page). In addition, I analyse the 'actant' concept as I argue that this concept could prove to be very useful in any analysis of engineering. The concept, with its background in literary and narrative theories (Greimas, 1987:106; Kristiva, 2002), has found its way into science and technology studies (STS). Here the concept is given a specific meaning as holder of certain positions in a network and, perhaps controversially, without distinguishing between human and non-human actants. This is criticised by Pickering (1995), and in the latter parts of this paper I will follow this critique and investigate to what extent the manipulator may be termed an actant, and how this approach can inform us about the relationship between engineers and technologies.

This paper is divided into two parts. First I will address the story of Jacob, which he told me during several meetings throughout the course of the project; this is supplemented with some meetings with Jakob's boss, James, who also relates his story. The second part of the paper addresses the concept of actant and I argue that the concept actant cannot stand alone, as it needs to be part of a network or world.

PART 1: DEVELOPING THE MANIPULATOR

The manipulator was designed to lift boxes of electronic stuff into the cabinet housing the control devices. There are several reasons for introducing this manipulator. First of all, it should spare the technicians the physical effort of lifting up to 50 kilos, which corresponds to the weight of the largest boxes. So, it is a sound and necessary

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construction installed for health and safety reasons. But it is more than that. It is also part of the larger plan to automate and modularise the production process of the control devices. In the previous process, control devices were assembled by hand, but in order to industrialise the process, automated processes are introduced and the manipulator may be viewed as representing one of the first steps in this new process; one of the first steps in implementing the larger plan on automation/modularisation.

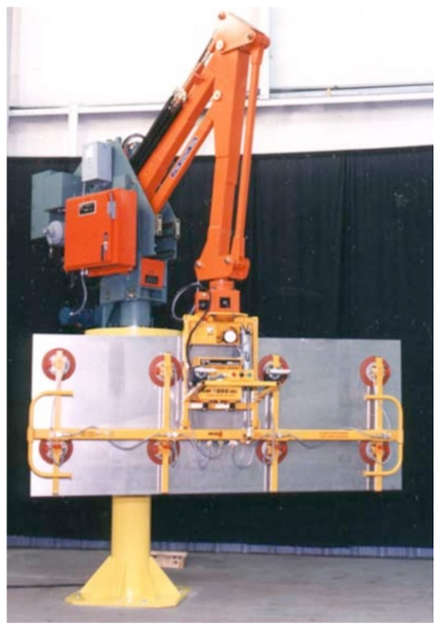

Figure 1. A manipulator

The simple reason for this is that the handcrafted cabinets could be filled with boxes from all sides, meaning that the technicians could operate the cabinet from both the front and from the back. With the new cabinets intended for industrial production, this is no longer possible. They are now only accessible from the front of the cabinet and, therefore, the assembly process becomes more difficult for the technicians. A traditional crane is not an option, as it is impossible to lower things down into the cabinet. The manipulator should solve this problem for the technicians, hence becoming a first step towards a fully automated production process.

The development of the manipulator project was initiated in early 2009 at the same time as the new cabinet design was introduced. At first glance, this looks like smart thinking as both product and process developments occur simultaneously. At a general level the manipulator seems to be a simple enough task and a straightforward enough project for a qualified production engineer – a lifting device that could be specified in advance, together with the new boxes. It could even be bought off the shelf from a known reliable supplier.

But this was not how all this turned out. Throughout the project, the manipulator was beset with delays, changes in project management, technical problems, and communication problems between the partners involved. So, what initially seemed to be a relatively straightforward journey, turned out to be anything but.

Situation, March 2011: The manipulator is a piece of standard equipment, but to each manipulator there is a fixture, a mounting device, a tool that must be designed to fit each individual box of electronic devices. These tools should be designed and produced individually. This was a tricky task. The original idea was to standardise the process and standardise boxes, tools and manipulator simultaneously; but, according to Jakob, this was not possible, as only approximately sixty per cent of the boxes had been standardised leaving the vexing issue of how to manage the other forty per cent.

Jakob: *When I entered the project, I decided to follow another route, where we had a flexible tool. So you had, instead of four fixed joining points, so you could change it in a way.*
Q: *Yes.*
Jakob: *So you could hit some more boxes.*
Q: *Ehm ... But it is not a solution in the long run, if it should be automated?*
Jakob: *No. It is not. That is a solution for the new products we are rolling out now.*
Q: *Yes.*
Jakob: *So, eh, from my point of view, this is about doing this stepwise. Eh, so there is still, still … there is a solution for each step.*

The flexible solution is not a sustainable solution in the light of standardisation and modularisation; the boxes are not fit for, or ready for, future automation. But according to Jakob, this situation will have to do for now. This is the only way the manipulator project can get any further. It would not be possible to demand a fully-fledged automated process when only sixty per cent of the boxes were capable of conforming to such automation constraints. Instead, Jakob had to come up with something else; a flexible solution that was able to handle different kinds of boxes demanding different kinds of tools.

Jakob informed the development department about these problems and told them that the boxes should be standardised so that they were ready for front mounting by the manipulator. However, because Jakob's department (Production preparation department, PPD) was a relatively new department, and there were a lot of other tasks concerning start up of the department, no one really followed up on the manipulator project and in those hectic start up days it appears that everybody in the department more-or-less forgot about the project. In essence, nobody really cared about this project (Henriksen, 2011).

The first project manager, the engineer on the project from the beginning, contacted a lot of people, trying to convince them that they should assist on the manipulator project. Different external suppliers making the mounting tool, suppliers of the manipulator itself, the security organisation, the people in the prototype workshop making the boxes, and of course the project managers in the factories that wanted to know how to make the new products. But because of the delays, they all became very frustrated when they heard about the manipulator.

Nobody cared for the manipulator. Jakob talks about the frustration:

> *And there the manipulator is a decisive factor, and because it has just been one big question mark … it is an unknown technology for them (the people involved in the manipulator project) and sometimes they are drawn in to it ehm … and are told that yes, but this is something that should look like this, but we do not quite know what it will cost, and we do not quite know when and how … So, we have started a process, but from there, they have heard nothing. At least that is what I hear. No one said, 'we close down the manipulator project for a period of time, because we do not have the resources' and such, so, eh, people were sort of left in a kind of nothingness.*

They knew that there was a manipulator somewhere, but they did not know where and when. And then there was the problem of costs. The factories should pay for the manipulator, and they would be compensated in their budgets, but they did not know how much. Would it be forty thousand kroner or would it be six hundred thousand, they simply did not know. At the beginning of the project period there was plenty of money available for the manipulator project, but later this changed. All these insecurities caused a lot of frustration and most would rather not hear anything more about 'this manipulator'.

Two years into the project Jakob was placed in charge of the manipulator. His first task was to engage with all partners in the project. But there were more concrete tasks as well. The flexible tool that holds the boxes while mounted, for example, had to be ordered from a subcontractor.

> *Jakob:* *Well, eh, where I have specified it (the tool) and verified the solution and so on. I have been very much into it, because I have been a (machine) constructor before. So, it is really my proposal for a solution, etc. Ehm, but they (the external supplier) just make it because we have no workshop.*
>
> *Q:* *But it is a special fixture that holds the box?*
>
> *Jakob:* *Yes, that's it. It's actually just one … a base plate with four pins, with the four pins then locking into the base plate.*

Next up was to test the tool to make sure that it actually did work, that it is able to lift the boxes, and to lift them with an uneven load etc. After that it was time to find a suitable brand of manipulator, as there are several brands on the market. And then there was the control system between manipulator and tool, this has to be made and tested as well. And finally, the entire system of manipulator, tool, control system and boxes – it has to fit together and be tested and then sent out to tender, because several suppliers can bid for the tender.

Jakob notes that he actually designed the tool:

> *It's a bit special. There was someone who said to me before I started at The Company that in The Company you will not be assigned to any tasks. And this is really true – you take them on yourself. Ehm, because in our department, we have no one who can draw and stuff, well modulate. But I could, so, based on my background (as a machine constructor), so I have … I just said 'well I'd like to have CAD programs (Computer Aided Design) and things like that' and I got them. So you could say … had it been someone else in our department, then it would probably have been put out to a subcontractor to come up with this concept. But I carried out the conceptual part myself, you see. Of course, you talk to the others, etc. So it was a fairly mature proposal that was sent to the supplier.'*

> *Q:* *You then send this to a company where there was an engineer, pulling his hair, shouting 'this is impossible'?*
> *Jakob:* *No, in fact he did not, because he had been one of our consultants … he knew of the project, so … then it is the prototype and the tender.*

According to Jakob this is simply a classic engineering task. He had to design a series of different fixtures fitting the different boxes – thirty in all, and then test them to see if the system worked well, if the tool could hold and then release the boxes, and so on. Throughout the tests Jakob is in contact with the factories, informing them about his progress. Because of the delays it was important to constantly inform everybody and to keep reminding them of the project. At this stage Jakob was quite optimistic about the project, *I think we will be ready to launch the project this summer – I hope.*

Situation, June: The first manipulator, at this stage, was installed in the prototype workshop – a big orange beast that worked quite well. This one was an off-the-shelf standard type, pneumatic driven, and rented from a sub-supplier. The tests were performed on this rented machine; however, this was not the manipulator that was to eventually end up in the factories. Firstly, because it was driven by air and pneumatics had been abolished for a long time in the factories, as it is inefficient, very noisy, and sometimes dirty. Secondly, because the manipulator that is to be used in the factories is driven by electricity, and it is to be specially made for the purpose by a local equipment supplier to The Company. There were some discussions about this. Some said that they should buy manipulators from known suppliers on an off-the-shelf basis. But it turned out that the manipulators available were too big compared to the load they could bear; they were also too expensive. It was therefore decided to have them custom-made. Thereby it was possible to have a smaller, cheaper and better solution, even if this would take some more time. The new machines are slightly different from the rented one.

The orange pneumatic driven machine almost completely overcomes the force of gravity; loaded with fifty kilos it can be operated with a mere fingertip. This is not possible with the new manipulator. But there are some advantages. In particular, the point of fine positioning of the boxes in the cabinet was seen as a big advantage. At this stage there were also some questions about the operation of the new manipulator, the control system, buttons/switches, and things like that. This was to be settled in cooperation with the supplier building the new manipulator. Jakob did not see it as a problem that the manipulator used for the tests was different from the new one. It was deemed helpful to be able to rent a manipulator to perform the tests as it was cheaper, and it was possible to learn from the rented machine and get the final equipment right first time. According to Jakob it would have been impossible to make the final manipulator without the learning and lessons gained from using the rented one. The rented, air driven, manipulator taught Jakob that it was actually possible to mount boxes in the cabinet from the front. So, this knowledge was invaluable when it came to designing and building the new manipulator. If he had ordered a new manipulator at the cost of approximately half a million kroner, and then started testing, and then found out that it was useless for the purpose, then Jakob and his department would be in deep trouble. But with the aid of the rented manipulator it was believed that this would not happen.

The new manipulator was constructed in cooperation with a local machine supplier. This is a negotiation process where Jakob visited the supplier once a week and was in contact with the supplier through phone and e-mail on a daily basis. So, this was a very close cooperative venture. In the process it turned out that the supplier was already involved with other projects in The Company, but Jakob was unaware of this, which he found very strange. No one had informed him, but according to Jakob this was not a problem, just a curiosity in a big company. The cooperation with the external partner went well and at this stage Jakob was very optimistic about the project's progress. The new manipulator was well under way, and the tests of the tools on the old manipulator were satisfactory. These tests were given special attention, as the tools would become a future bottleneck if they did not work appropriately. 'This just has to work first time', noted Jakob.

There were, however, some concerns. One of them related to economics and project cost. When the manipulator project was launched in 2009 there was plenty of funding available for the project, but as nothing happened in the project the first year these funds seem to have disappeared and in the summer of 2011 the funding is now based entirely on the factories' budgets. This could turn out to be a problem; for example, one of the factories needs four manipulators, but only had a budget for two. What he should do about this, at this time, Jakob did not really know. Jakob, however, was quite confident at this stage in the summer of 2011 – 'I will have finished this project by the end of September'.

Situation, September 2011: The project was not finished at the end of September. The first three manipulators were delivered from the supplier and they were successfully installed in the factories – two in the Danish factory and one in Spain. But there were some problems.

Jakob: Ehm, I had severe problems in-house. I was only allowed to take a few boxes for testing.
Q: Well. Why?
Jakob: Well, eh, eh because there has been so many changes made, etc. so there was a backorder on products, you know; for simply being able to get these boxes and these cabinets that we need to test on.
Q: So, you were not allowed to take them?
Jakob: No, I was not. And I spent so much time on it. An awful lot of time – just to get something.
Q: Who was it, who said no?
Jakob: It was the projects. They would even use them for their EMR-production, you know, their productive output, but eh … but I finally got one. It was not what I wanted to have, because I would rather have had the most difficult ones, just to make sure that it was good. So, eh, much of it … we could only test virtually, in the 3D CAD.

Jakob was present at the factories when the manipulators were installed; first in Denmark and later in Spain. In Spain he took the entire crew from the Danish factory with him to make sure that everything was done correctly. This was in mid August and everything went fine, except for some technical problems. It turned out that the tolerances on the Spanish cabinets and boxes were smaller than expected, so the tool had to be changed and there were some minor niggles on the manipulators installed in the Danish factory. Things that could have been avoided if there had been a prototype, but now these things were being handled and everything should be OK. Then there were some safety aspects.

Jakob: Ehm. But then, there has just been a case here a few days ago … out there (in the Danish factory) where the … eh, they drove the gearbox to pieces and there was a lot of controversy around the 'arrr and the security in it' and things like that. And they spent the whole day out there yesterday, at the manufacturer, and together with their programmers, but they just couldn't figure out what it was. But they had changed the parts that were broken and things like that. And it turns out, after all this, toward the end of the day that eh … the operator had spent some time on a warped box, and there are these four security pins for their safety and the fourth pin did not work, and he had just put a screwdriver in there. And that worked. Then all of a sudden he had bypassed all its security, so there was just a little controversy there.

After this incident, the plan was to make the final SAT-tests (Site Acceptance Tests) in the middle of September and get the security/safety organisation involved. Normally they would have approved the manipulator in the prototype workshop, but as there was no prototype they would have to make the approval on site.

Situation, December 2011: In early December the manipulator project was almost finished and Jakob had already been assigned to other tasks. By this stage, four manipulators were working in the Danish factory and one in Spain. This all looked pretty good and the people in the factories were quite pleased with what they got. Since September, when the first manipulator was installed, there had only been some minor technical problems that could be handled without much ado. It was a problem though, that the manipulators were produced and installed without test running a prototype.

Jakob: *They've made some changes, eh … some things have been mistakes, if you can call it that. 'It was not what we agreed upon. It had to be able to do this' or 'it should not be able to do that' simply for security/safety reasons. And then, there have been some things where the … eh, when we had it going because we had not been allowed to make the prototype here.*

Q: *Yes, there was no prototype, no?*

Jakob: *Yes. Ehm, there have been some times where we said 'Oh, it would be nice if …' … An example would be when this tool is fitted into the cupboard, it's actually quite difficult when you stand behind it, well, it has got to be completely vertical when you put the base plate into it. So we mounted a small target plate on the side of it, so you just had a kind of indicator to align it with and things like that.*

Q: *Yes.*

Jakob: *Such small things like that. And it is something that is usually resolved with a prototype, right?*

So, instead of changing one thing in a prototype, Jakob had to change all five manipulators already working. Then there had been some issues with personnel training, some instruction was needed, but according to Jakob this was foreseeable, there would always be some complaints at the beginning.

Jakob: *But then it (the complaints) faded out pretty quickly, actually, I think. Along with the people who are not on the shop floor, the engineers out there, we made a list (of remaining problems) which we have reduced by now. And eh, now here, now I hear nothing about it, anymore.*

Q: *Okay. And you take that as a sign, now it's okay.*

Jakob: *So, eh, when I am out there (in the factory) I say 'just try to look out (into the factory) and see if they actually use the manipulators.' Just to make sure.*

Q: So it is not standing idle in a corner and not being used.
Jakob: Exactly, right? I just want to be sure.

At the factory in Spain it went almost as smoothly, but the aforementioned problem with the tighter tolerances surfaced once again. In order to be able to use the manipulator it was necessary to relocate an electronic box on the side of the manipulator and a technician was sent down from Denmark. He fixed it on a Friday, but Monday morning the Spanish engineers complained that the box was not relocated far enough and the manipulator could still not meet the tighter tolerances. It turned out that the technician did not have the time to test run the alteration as the factory was closed down at two o'clock for the weekend; even if the factory manager had promised that he could stay the weekend. But, other than these minor incidents, the five manipulators worked in a generally satisfactory manner.

PART 2: ACTORS, ACTANTS, AND TOOLS

From our everyday conception of technology we know that technology is about artefacts. But how can we relate artefacts to an analysis of technology that will be capable of transcending the problem of conceptualisation of these artefacts? The conventional conception, in line with a Cartesian conception of things, entities, tools, equipment, technologies is that they are a collection of objects confronting the human subject (Dreyfuss, 1997:16). In this view man and tool are separated – the world exists as a collection of things which are there just for man to use. This conception is, however, problematic, because it does not tell us what the things are. On the contrary, the thing becomes even more remote from us. Man and world are separated and they can in no way relate to one another (Latour, 1993). But because this conception of things is so common and widespread, this could be one of the reasons for the problems we face when trying to find out what tools are. If man and thing are separated how should we then be able to relate to them and find a satisfying conception for them?

The conventional conception offers us, at least, three problems that need to be dealt with in order to understand technology (Pickering, 1995:5). The first problem concerns representation; that is, how do we conceptualise technologies? The conventional conception informs us that objects should be described in a scientific way where the correspondence between object and concept is our guarantee of a true description. This is highly problematic, as this would require a type of timeless epistemic knowledge, thus ignoring the temporal character of objects and, just as importantly, ignoring the objects' relation to actors and the joint world of objects and actors. This also points to the second problem of the conventional view, the timeless status of the representation. As we can observe in the history of the manipulator outlined above, the manipulator was definitely a story of changes – a process of constant changes and, consequently, we need to find a way to incorporate temporality into our understanding of technologies.

The third problem of the conventional concerns the objects themselves – are they just dead objects or could they play an active role in the process? This is the problem of agency and this is where the concept of actant enters centre stage. The manipulator is an actant. That is, it is a non-human actor that has a kind of agency; it is therefore important and it can influence the course of the story of Jakob and the manipulator. At first glance this is self-evident. But the focus here is the question of agency. Is it the case that the actant has any kind of agency and, if it has, how does such agency manifest itself? It would definitely have to be different to that of humans. With inspiration from semiotics and literary studies, actor-network theory (ANT: Callon, 1986; Latour, 1993; 1999:174) uses the concept of actant for any actor – human and non-human – in a network. The actant will take shape and get its role in the network through its relation to the other actants in the network as there is no essence in the actants.

From this perspective, the manipulator and Jakob are both actants, and they are granted their place in the network through their relations to other actants. But it is equally obvious that there are fundamental differences between the manipulator and Jakob – this is trivial, Jakob and the manipulator cannot replace one another and the manipulator was called upon to help operators lift and position heavy stuff, which these (human) operators could not lift themselves. The use of the concept of actant, as used in actor network theory, has been criticised for levelling this difference.

Pickering (1995), who is sympathetic to actor-network theory (ANT), acknowledges this critique in wishing to maintain a distinction between human and non-human actants. In a previous debate on the matter with Collins and Yearley (1992), it was argued that the question of studying material agency would end in a dilemma that actor network theory scholars could not escape: either we would study how scientists make accounts of material agency becoming ordinary sociologists, or we would ourselves study material agency and becoming scientists. Callon (1986) and Latour (1993) escaped from this problem by maintaining that it was a question of semiotics and human and non-human actors should be treated symmetrically when networks were analysed with semiotic methods. In this way, they elegantly avoid the question (of the difference between human and non-human actors), but also reduced it to an epistemological one. Pickering is not satisfied with this, and maintains that 'semiotics cannot be the whole story about the actor-network understanding of nonhuman agency' (1995:13), because then we will again be confronted with the problem of representation that actor-network theory tried to avoid in the first place. Instead Pickering confronts the problem in the following way by maintaining the idea of material agency while avoiding the problems that Callon, Latour and Collins and Yearley face. Pickering's answer is both obvious and simple; he wants to introduce time and process to the analysis of human and non-human agency.

Simple, because by changing from an a-temporal to a temporal analysis, it becomes possible to analyse the changing positions of both human and non-human agents. According to Pickering, the temporal analysis puts social scientists and scientists on an equal footing when it comes to the study of material agency, as neither of them knows the outcome of the development process that is science. This also points to why it is an obvious move for Pickering to make. First, because the words and concepts we use are time related; actors, actants, agency are all concepts that connote action, change and therefore something temporal; consequently, this cannot be studied in a timeless way (in sequences of timelessness, Henriksen et al., 2004). Secondly, because this argument has already been brought forth by Kristeva in the original debates on actants in literary studies (Hardy & Agostinelli, 2008; Kristeva, 2002) as well as and by Latour (1999) when he talked about half finished objects. Actants will change status over time and temporality should therefore not be viewed as something new to the study of actants. Pickering calls this process 'the mangle of practice'; that is, a process where human and non-human actors are 'intertwined' in order to pursue a certain goal (like, for example, science and scientific insight).

Pickering, very rightly, points to several questions concerning temporality, representation, and the agency of material matter. He also proposes the mangle metaphor as the means to describe and understand the process of science wherein both human and non-human actors take part. It is a process where scientists make apparatus, which in turn makes data, in a continuous process of dialectical trial and, most often, error. In this process both the human (the scientist) and the non-human actant (the apparatus) are active and consequently have agency.

In many ways this process is similar to Latour and Callon's process termed 'translation' (Callon, 1986). They are both concerned with material agency, the translation process (the mangle), and human and non-human interaction. The processes described by Callon and by Pickering are also, in many ways, similar to the conceptualising method (Henriksen et al., 2004) and its (rudimentary) ideas of material logic. The question now is how such a process description would be able to capture the complexity of a technological development process like the manipulator. In many ways it could, as they are ways of describing processes and they are attempts to describe the interplay between human and non-human actants. It also contribute with a deeper understanding of an important aspects of engineering practice taken the outset in open and wicked problems and becoming a crucial part of the constitution of the divides between problem and solution that is a result as much as the starting point for engineering practices.

WHAT IS AN ACTANT?

My initial question concerned the concept of actant and how it might inform us about Jakob's work on the manipulator. Latour, Callon and Pickering all present some very interesting theorising about the matter, and they all confront the three questions mentioned above: representation, agency and temporality.

Addressing the issue of temporality first, it is patently obvious that description and understanding of actants, tools, and technologies are temporal; it is a process. The manipulator was not merely an entity; the manipulator is best described as a project. During the course of the project it was changed several times. Changed from pneumatic or air driven to electrical, from large to smaller, from orange to black, from rented to newly built, and so on. Its lifting capacity was important, not a specific entity. The process that produced the manipulator could definitely be described as a translation process (Callon), or it could be a 'mangle' (Pickering). It was also a conceptualising process (Henriksen et al., 2004) as Jakob and his colleagues had to develop a new language for the manipulator. Dreyfuss (1997) informs us that the tool would be part of somebody's world, and in the case of the manipulator this world also had to be created, as this world should hold the manipulator. So, the manipulator is understood by describing the creation of the world that it is going to be part of; and this is a description of a process (Dreyfuss, 1997). With Dreyfuss we could say that in order to make the manipulator happen, Jakob had to disclose a new world, namely the part of The Company that produced and used the manipulator. Based on the story of Jakob and the manipulator we may now very plausibly describe engineering as a process, which the 'ing' in engineering also indicates.

The second question is that of agency. From all of the above, it is clear that the conventional concept of object is of little, if any, use to us here. The manipulator was not merely just an object. It had to be outlined, designed, constructed; and throughout all the process, the manipulator was very active. When asked about the status of the manipulator, Jakob very much liked the idea of agency and a negotiation process (translation, mangle, conceptualisation, disclosure).

Q: *And it was the first thing I wanted to talk with you about, it was whether it made sense, to talk about manipulators as an active player.*
Jakob: *Well I think, certainly, that is how I always looked at it myself.*
Q: *It eh, it has its own, what do you say, will?*
Jakob: *Yes.*
Q: *To do things, and especially to prevent things from happening and also being part of a negotiation process as we talked about.*
Jakob: *Yes. Well it … It eh, it's 100% the way it is, that is because there were two places where I had to convince people, or three perhaps.*
Q: *Yes.*
Jakob: *There is down here (in the prototype workshop), ehm. The people who are down in the factory, down here, the ones I've consulted, and had them on board the process of what it should look like.*

Even if Jakob was mostly concerned with the negotiation process (I had to convince …), this idea of agency was not foreign. In a workshop, held with Jakob and his colleagues, the same question was asked; several engineers liked the idea and some of them just shook their heads in disbelief. Yet none argued for the object option; the manipulator was not simply dead matter to them. The idea of passive resistance also makes sense. Every time the manipulator broke down, or did not work as intended, it unequivocally demonstrated its agency. It initiated a number of actions that were necessary in order to get on with, or progress, the project.

It follows that we have granted, or recognised, tools' agency, but what should they be called? Latour terms all participants as actants. At the workshop, the engineers strongly argued against this. They were perfectly in tune with Pickering's interpretation and would not accept any interchangeability between human and non-human actors. Instead the workshop group settled for a compromise, where humans were called actors and non-humans were called actants. This, from my perspective and background, is very plausible; firstly, because it is in line with the conceptualising method (Henriksen et al., 2004), and secondly, because we can distinguish between humans and non-humans while still being able to grant agency to the latter.

This brings us to the third question, the question about representation. From all of the discussion up to this point, it is patently clear that we cannot settle for a simple description of an object, with correspondence between object and description. The timelessness of such epistemic knowledge forbids that. More is needed. This is not to say, though, that such descriptions are un-necessary. On the contrary, they are essential to the engineer's work and Jakob made several such descriptions during his work on the manipulator project. He made lots of drawings, calculations etc. and the quality of these efforts were all evaluated for their correspondence to actants on the factory shop floor. But even if they are central and definitely indispensable, they cannot relate to us the whole story of the manipulator, as they then would only be present-at-hand for us (Heidegger, 1927/1995:69). Instead, we need a narrative that describes the change processes and the entire world that the actant is part of. Such a narrative could be established in several ways. Collins and Yearling (1992) argued that the study of sciences made by sociologists would be a study of scientists and not of science, as scientists themselves could only make that. In some sense they are correct, as I was not present at the drawing board, in the workshop, or on the factory floor. I only came as a visitor and I only know of, or about, the manipulator through Jakob's story. But this only positions me similarly to Jakob's colleagues and his boss, James.

In a conversation with James, Jakob's boss, I asked him about the manipulator:

Q: *So, it's funny that you mention all the people who are around the manipulator, but not actually talking about manipulators. It's just there.*
James: *Yes, it's just there, yes. But it's true.*
Q: *And then sometime in between … then it will not play with you?*
James: *Yes.*
Q: *For example in the factory down in Spain?*
James: *Yes.*
Q: *But otherwise, so, so we do not hear much about it.*
James: *No, you know, for me, for me, it's probably because I have difficulty talking about it, because it's such a piece of equipment that I cannot really … I do not really know about it.*
Q: *No, no, no.*

James: *But the context it must be part of, it is enough that I … that is what is my role, it is the interface, it is these meeting-points, the stakeholders have to be satisfied. So for me it's very much about … yes it sounds like, but it is stakeholder management, and it is about avoiding any controversy, hassle, trouble.*

Q: *Yes.*

James: *Because I will not be involved in it, because I do not know, so I do not know anything about the equipment, so the better I can support Jakob in making sure that he communicates with the right people and get … so it will not get out of hand.*

James and I were in the same situation; we were left to hear from Jakob about the state of affairs on the manipulator project. So, in this sense Collins and Yearling (1992) were correct. On the other hand, both James and I have a background in production management (James as a PhD in production management, and I as an educator of engineers for many years), we understand the language of that world, and therefore also understand the language of the world that holds the manipulator. We also both tried to discuss matters with Jakob, as when James tried to assist in political matters concerning the manipulator, and when I tried to introduce new concepts such as actant and negotiation process. In this way we both tried to assist when Jakob was disclosing a new world (Dreyfuss, 1997). It follows that we do not need to become like Jakob to get to know about the manipulator (Collins and Yearling); and we do not need to become actants either (Latour). When we were assisting in disclosing the new world (Dreyfuss), and when we tried to assist in conceptualising (Henriksen et al., 2004), the little we could do was sufficient to get to know about the manipulator. Therefore, the question of representation is, if not solved, then dealt with in a manner that will pragmatically do enough, or satisfice, for now. The problem of representation is ever-present and will eventually surface in any project concerning engineers, technologies and the worlds they try to create. Both Jakob and James were very well aware of this. The manipulator project had been a learning process for both of them and they wanted to make use of that learning in future projects.

Jakob: *Ehm … Well, then we held a follow-up meeting, some 'Lessons Learned'-like meeting. Because this is actually one of the first, it's actually the first project that has run through via PPD. Eh, 'what are the procedures now, for this?', right? Because there's a lot of things that did not run smoothly. First and foremost, there has been a wealth of project managers from all projects.*

Q: *Yes.*

Jakob: *And it is probably never an advantage. Ehm, and ehm, then we talked about whether we should use a procedure like we have a process for producing prototypes and test equipment.*

Q: *Yes.*

Jakob: *And this is something that operates as a small staff project for the major project, you know, the main project (that is, automation on the factory floor), right? And it was probably the way to do it with these pieces of standard … when we develop standard equipment. And try using some of the same business practices there.*

Q: *Yes.*

Jakob: *Or, project procedures.*

Q: *Have you learned anything from it?*

Jakob: *Yes, certainly. Definitely. So, but, but, eh, it's been a lot about 'how are responsibilities shared?' How is … who should pay what? And who pays the man-hours? And eh, who is really in charge of what we decide? Who is it that has the last word on this?. Because it's not everything we can agree upon.*

Q: *No, no.*

Jakob: *So, so, eh, there we make just such a little 'lesson-learned' on it, and then, eh, we have a task that was … in our huge task-book about it, to look at the procedure for ordering standard equipment.*

Q: *Are you wiser for the next project?*

Jakob: *Yes definitely. Absolutely. Well, because now I can do it second time around, right?*

Q: *Yes.*

Jakob: *But, eh, but it has to be so, that we can all do it, right? Because I've had my experiences on how to do it, and eh, I could not have done it, even with what I know now, because I was not there from the start of the project. So, ehm …*

Again, it might seem strange from a rationalistic position that Jakob is so concerned with the process. When asked what he learned he talked about the process, the negotiations, the conflicts etc. He did not talk about drawing, design, calculations, and manufacturing. But as a disclosure of a new world, as a conceptualising process, there were definitely lessons to be learned and even the question of representation seems to be a question of describing and also learning from such a process. This contributes to the understanding of how the 'wickedness' of problems to be solved goes beyond the mere technical aspects of solving well defined problems and open basic question on how problems emerge are constituted and consequently considered objects of engineering practices.

CONCLUSIONS

Jakob managed to make the manipulator project into a success story. And this success story can inform us about the relationship between an engineer and his or her creation, between actor and actant.

Q: *Just one final point.*
Jakob: *Yes.*
Q: *The manipulator, have you ever dreamed of it at night?*
Jakob: *No.*
Q: *Well, OK .*
Jakob: *In general, I never dream about my work at night, fortunately.*
Q: *Well OK, it has not been so bad.*
Jakob: *No, no, but ehm … It has been a problem child, yes, right?*
Q: *But when I talked to James, he was more than reasonably happy with what had happened, he said. So you really should be commended for …*
Jakob: *Well, it has …*

From Jakob's story, it is obvious that a conventional idea of subjects (Jakob) confronting objects (the manipulator) is of little relevance here. The story of the manipulator is better understood as a process, as a process to deal with the manipulator and deal with Jakob's relation to his creation. From this we can conclude that the manipulator is an object, an actant, an artefact, a piece of equipment, a tool. It was an object for engineering design when Jakob planned, calculated, and created the original drawings. And it was an object when the gears were driven to shreds and Jakob and his colleagues concentrated on fixing it; in this respect the manipulator was present-at-hand for them. It was also an artefact and a piece of equipment. And it was an actant when we use the language of STS and of the conceptualising method.

But it was much more than that. It was also a process and it was part of a world. Tools and actants are part of a world where the actant is 'intertwined' (Pickering), translated (Callon), and active (All of them) and they are also constitutive of these worlds; it follows that they are all necessary in order to understand the process that made the manipulator. For the engineer and for engineering this is very important. Constructing a device like the manipulator is not just about designing, calculating and drawing as part of engineering practice. It is just as much about disclosing a new world, conceptualising, translating in the mangle.

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12. GENDER AND PROFESSIONAL PRACTICES IN SOFTWARE ENGINEERING

INTRODUCTION

In this chapter, I investigate how software engineers account for their professional practice in three different sites and cultural contexts, Norway, Malaysia, and California, and what role gender play in their accounts. I am exploring how they describe their work tasks, practices, skills, motivations and experiences, and where and how gender surfaces or become relevant in these accounts. The aim is to explore how software engineering work is gendered differently across contexts, and particularly contexts with different distributions of men and women in software engineering.

The study was triggered by the observation of considerable gender imbalances across the sites. Thus, the study is a multi-sited analysis (Marcus, 1995) and the different contexts represents a challenge but also a source for providing a more nuanced perspective of gender and professional practices in software engineering.

THE GENDERING OF SOFTWARE ENGINEERING

In a western context, literature has often identified cultures, norms, identities and practices in engineering as gendered 'masculine' (Frehill, 2004; Faulkner, 2001; Kidder, 1981; Wajcman, 1991, 2004; Woodfield, 2002). E.g., Wright (1997:438) argues that occupations or fields dominated by men will produce a 'masculine' culture and an 'occupational masculinity'. The latter is defined as a concept of material features (behavior, identities, experiences, relationships, practices, and appearances) and discursive features (language and relationship discourses) that are generally attributed to men more than to women (Collinson & Hearn, 1994). Within engineering, an 'occupational masculinity' characterizes a passionate and intense relationship with technology (e.g, Mellström, 1995; Robinson & Milwee, 1992). Moreover, the culture of software engineering has been described as 'an occupational culture of computing' (Sproull et al., 1987) or as 'the occupational masculinity of computing' (Wright, 1996). These concepts have been linked to cultural norms of being overly enthusiastic about and/or absorbed in computers (Rasmussen & Håpnes, 1991; Sproull et al., 1987).

However, Murray (1993) has articulated another software engineering masculinity that diverges from the technically consumed and 'narrow-minded' engineer.

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> *The ability to give a little extra effort, to work odd and often long hours and the possession of demonstrable competences in the discourse and techniques of 'milestones, deliverables and objectives'. Increasingly, it is about having the right methodology and being a 'software engineer'.* (Murray, 1993:73)

Murray argues that this mentality represents an elongation of the software culture portrayed by Kidder (1981), of computing as a macho world, characterized by intense dedication, hardship, immense will power and extreme work hours.

On a different note, some information systems scholars have also depicted software engineering as a hybrid, focusing more on non-technical elements, like communication and 'social skills' (e.g. Brookshire et al., 2007; Dahlbom & Mathiassen, 1997; Goles et al., 2008). A version of this assertion has often been used in efforts to include more women into software engineering education, partly by arguing that women are better software engineers because of their particular 'feminine' skills, which include being more concerned with users and usefulness. This as a contrast to narrowly technically oriented men, that have been portrayed as less valuable as software engineers (Lagesen, 2003, 2007; Woodfield, 2002).

Such attempts of 'feminizing' aspects of software engineering may be found in some strands of feminist research of technology arguing that Information and Communication Technology (ICT) will offer women an increasingly prominent role in relation to computer technology, due to their alleged superior communication skills compared to men (Kirlidog et al., 2009; Moore et al., 2008), and what was seen as women's profound interest in communication (Spender, 2003; Wakeford, 2003; Plant, 1996).

However, such predictions have been countered by empirical studies, like Woodfield's (2002) who found that even if managers in a software engineering companies said they preferred people with hybrid skills – and they believed women to be the best hybrids – in practice, women employees did not benefit from this assumption. According to Woodfield, hybrid men were still preferred over the hybrid women because men's assumed technical skills, were nevertheless seen as more important as the basis for selling products and services (Woodfield, 2002). Similarly, Lagesen and Sørensen (2009) found that the 'social' in software engineering was depicted as a 'natural' ability, while the 'technical' was perceived as a professional skill. Thus, there has been a tendency to dichotomize 'technical' and 'social' skills, which have been attributed a gendered meaning in the sense social skills have been depicted 'feminine' and technical skills 'masculine' (Faulkner, 2000). Still, scholars have observed a discrepancy between what people actually did and how they talked about their practices (e.g. Faulkner, 2007). Thus, we see how practices in software engineering have tended to be interpreted in particular, and often gendered, ways.

Instead of attempting to search for essential gendered features in software engineering or to establish a general framework of social and cultural factors that can explain gendered practices, gender can be analyzed as ways of making sense of practices. Gender appears in different shapes and forms, and only exists in relations. It is never 'pure', thus, we cannot separate out gender as an entity as such. Gender is discursively related to stereotypes or to an alleged or anticipated difference between men and women (which label 'sex') It appears in a situation, always related and that is why the concept of assemblage is useful pointing to the heterogeneous and elements linked to become constituents of gender (Haraway, 2004; see also Latour, 2005; Lagesen, 2012)

> *Gender is a verb, not a noun. Gender is always about the production of subjects in relation to other subjects, in relation to artefacts. Gender is about material-semiotic production of these assemblages, these human-artifact assemblages that are people. (…) Gender is specifically production of men and women. It is an obligatory distribution of subjects in unequal relationships, where some have property in others.* (Haraway, 2004:238)

As a way to study gender in relation to other differences, the concept of interference has been argued to be a fruitful theoretical tool (Moser, 2006; Geerts & van Turin, 2013). Interference was originally introduced by Donna Haraway (1992), as a figuration or metaphor to describe how realities are made and enacted, and how differences interact with each other in ways that make disturbances, create new orderings, produce new identities, or also create new differences, in short produces effects. Interference also refers to how the scientist as such interferes with her research, and how the interference should be made part of the analysis, as a way of situating the knowledge.

In this chapter, the concept of interference will be utilized as an analytical tool for studying how gender potentially interferes with practice and is discursively co-produced with aspects of the profession, for then to see what effects it may create. 'Gender' is interpreted as closely related to the cultural constructs of 'men' and 'women' in relation to their professional practices. As many poststructuralist gender scholars have argued, the fluid meaning of gender is related to the biological sex, but in an ambiguous way (Butler, 1999; Moi, 1999). How did our interviewees enact gender (or not) by making associations to the social and cultural categories of 'men' and 'women'? How was gender made part of interviewees' accounts of software engineering work? I thus analyze how gender was enacted (and not enacted) in relation to various aspects of software engineering *and* how this may vary in different cultural contexts. How was different gendered associations articulated in different software engineering sites and how was cultural context enacted in these associations?

As Kanter (1977) pointed out, men and women are in themselves gendered symbols. This suggests that gender may be produced and reinforced through observation of visible 'men' and 'women's' bodies. This line of thought does not mean invoking a less constructivist understanding of gender. On the contrary, the argument is that the visible body interferes with gendered associations and that the symbolic materiality of bodies becomes a part of the interference, similarly to other forms of materialities like technology, institutions, etc. Thus, the argument should not be read as a simplification of gender, but rather is a point of departure for an analysis.

METHOD

The research is based on qualitative interviews with men and women software engineers in software engineering- and consultancy companies in Norway, Malaysia and California.

Why did we choose these particular sites? Even if the issue of number of men and women have often been dismissed as an important concern for gender studies (see, e.g. Gherardi & Poggio, 2002) the number of men and women may influence gender symbolic properties of a profession (Lagesen, 2007; see also Faulkner, 2009). Gender imbalances were an entry point to the design of this study. A vast western literature has shown how software engineering has been, and still is, dominated by men. However, quite striking variations may be observed and between the sites investigated here, there are considerable differences. Moreover, the sites represent different contexts with respect to equal opportunity policies and discourses about and efforts toward inclusion of women to software engineering.

In Norway, as in many other North-European countries (Schinzel, 2000), the number of women has been low and ranged in 2008 between 10 and 20 percent (Sørensen et al., 2011). Norway have had a culture for using gender to explain social differences, a strong focus on equal opportunities for women, and relatively few women in software engineering (Sørensen et al., 2011). Norway is still a homogeneous country in terms of ethnicity. All of our interviewees were ethnic Norwegians. Despite its long-standing work for equal opportunity work, the country have one of the most gender divided labor markets in the world (Birkelund, 1992).

US has a higher number, approximately 30 percent, women in software engineering (Cohoon & Aspray, 2006; Bartol & Aspray, 2006). California with its iconic Silicon Valley is often considered a ‘hot-spot’ for software engineering. Here, concerns about gender issues have been less policy-related and policy driven, and mainly been efforts from NGOs and private organizations. There is a considerable range of organizations and private initiatives dealing with women and computing issues (Henderson & Almstrum, 2002). California is more heterogeneous than Norway in terms of ethnicity, religion and economy. Our interviewees consisted mainly of white ethnic-American, and a few Americans with a different (second generation) ethnic background.

In Malaysia, women constitute almost half of the work force in software engineering (Ng & Yong, 1995; Othman, 2006). Malaysia has had less focus on gender issues and equal opportunities. Software engineering has been a dominant strategy in the Malaysian society’s efforts to become a developed economy by 2020. This has made software engineering particularly attractive to women (Mellstrøm, 2009).

Malaysia is a multi-ethnic society and has had a history of interracial disharmony that eventually led to a constitutional policy to privilege Malays in the fields of education, employment, training, trade, etc. Ethnic and racial issues are highly noticeable despite political efforts to establish a pan-Malaysian identity that has predominantly focused on development of technology and the economy as a key measure (Williamson, 2002). The Malaysian policy has resulted in many ethnically divided companies and organizations. The two largest companies we did interviews in, were Malay-dominated and the third firm was a small multi-national company with a Norwegian origin. We interviewed only Malays, and an equal number of men and women in each company.

For reasons of anonymity, we have given all the companies new names. Interviewees have been given token first names that start with the same letter as their company, or a designated letter. Interviewees from Aconsult beginning with an A, from KomputerTech beginning with a K, etc.

The interviewees were selected to represent a variety based on sex, experience and position. We interviewed altogether 77 software engineers. The term 'software engineer' encompasses a range of different positions and job titles, like systems developer, advisor, IT designer, architect, project manager, consultant and senior consultant. Here, the term software engineering pertains to the making of information systems (IS), human-computer interaction (HCI), system development (SD) and software development. In the companies, no clear-cut distinction was made between those with a formal education in software engineering and those who had acquired such competence in other ways.

The author conducted all the interviews in Malaysia, most of the interviews in California, and all the interviews in one of the Norwegians companies. A PhD student student conducted some of the interviews in California and two master students did the interviews in two of the firms in Norway. The interviews lasted between 60 and 90 minutes and all followed the same semi-structured interview guide. They usually took place in meeting rooms at the workplaces, or in the interviewee's office, or in a canteen or somewhere else near the work place. The topics were; educational and motivational background, work history, job tasks, everyday-practices, learning and knowledge management, skills required and professional and social experiences in the work place. We did, intentionally not raise gender as a topic directly in the interviews because we wanted gender issues to be articulated by interviewees themselves. However, the outset for the study was also to investigate the interviewees reflections upon gender, as a way of situating the knowledge, particularly with regard to the 'gender production' in the interviews (Haraway, 2004; see also Lagesen, 2010). Thus, when the interviewees did not address gender, we prompted them in the end of the interview with the question of whether they thought it would have been different being a man/woman the job, and if so how.

All the interviews were taped and transcribed verbatim. They were analyzed by using a qualitative analysis program, Atlas.TI, made for grounded theory analysis which employs close reading of data, coding of data, and comparison of codes and clusters of code across data sets and/or within data sets.

THE NORWEGIAN SITE: SIMILAR PRACTICES AND DISCURSIVE GENDERING OF SOFTWARE ENGINEERING

Previous studies on software engineering practices have emphasized the dichotomy often made between 'technical' vs. 'social' aspects of the work, and the gendered interpretation of it, associating the technical with men and masculinities and the social with women and femininities (Faulkner, 2007; Woodfield, 2002). Did our Norwegian interviewees talk about their software engineering practices in such or related terms? All the Norwegian companies in our dataset offered consulting services focused on ICT, like project management, architecture, systems design and systems development. When we asked about what the main tasks were in performing their everyday practices, the most highlighted one was handling *contact with the customers*, like Anton, 32 years old and an IT architect:

> *(…) I have had a lot of the responsibility for developing the software we are going to deliver. That means I have had a lot of the contact with the customer, I talk with them, gather the demands they have, having contact with them, implement their demands, takes it back to the customer, and work with the customers.*

Since communication was so crucial in their practice, Anton also emphasized such skills as the most important part of his competence:

> *I think that [my strength] is my ability to communicate well with the customers. And I am very good at understanding problems and to see or configure how the solutions have to be.*

Actually, the majority of our interviewees said that being able to communicate properly was perhaps the single most important skill in the job. Peter, 32, mainly working with systems development, put it bluntly:

> *You can have people who are skilled, but if they are incapable of talking with people, then…it will be difficult to get what you want from them.* (Peter)

This resonates with the focus on hybrid skills (Brookshire et al., 2007; Dahlbom & Mathiassen, 1997; Woodfield, 2002) and was described as key by the interviewees. However, most also mentioned the importance of programming knowledge even if they did not really program anymore. Arthur, 33 years old and an IT architect, explained:

> *Well, you see, I can program, so I can read code and understand what's there. (…) You need to be able to talk with the programmer, and understand what kind of problems that may appear and make decisions.*

Thus, some programming knowledge was sufficient, but also crucial. A few interviewees also said they worked mainly with programming. These were commonly the youngest and most recently employed engineers, like Anette, 28, a newly employed system developer: *Basically I sit and program.* So far*,* Anette had not interacted with customers, but this was expected to change after her sort of 'apprenticeship'-period of programming was over. In another company, "Webdesign", they organized the division of labor differently. Here, also senior consultants did software development and programming. Walter, 31, and a senior consultant said:

> *Well, what I predominantly work with at the time is programming in Java. And databases. In addition to various Unix-competence and things like that. (…) But it is also important to be able to talk with the customers and things like that. We all deal a lot directly with the customers.*

Thus, also the interviewees who were mainly programming, stressed the importance of communication with customers. In general, gender was not that present in the accounts of practices and there were no reference to a gendered division of labor. The importance of having the 'core' competence of programming was emphasized by all, but perhaps even more by the women software engineers, because they felt, particularly as young women professionals, that they needed it to be credible in the eyes of the customers. Thus, programming knowledge was a larger issue for women employees because they had experienced that they sometimes were not being taken seriously as software engineers. Ann, 40, a senior consultant, reported:

> *I have been tested. For example, I have given courses a couple of times, a long time ago. And I had to use the first half of the course just to convince them that I knew what I was talking about. That is a typical problem. I have also experienced that they wanted to crack a joke in the break, and it is always the most sexist joke they can find.*

Thus, being suspected of not having enough competence was considered a 'typical' problem for women, and was mentioned by several of the Norwegian women interviewees (see also quote of Wanja below).

However, we see there were few traces of a gendered division with regard to "technical" and "social" skills though Ann pointed to a need to compensate for an undercurrent of sexism among colleagues and customers. However, more often interviewees offered gendered accounts of *other* men and women in software engineering like Arthur:

> *Well, there are many women who do not want to be isolated with a computer and only program for example. I think in general that women are more social, and have greater need to work with people than men typically have. (…)*
>
> *Interviewer: Hm … you said the same thing in the beginning of the interview, that you didn't want to program so much?*

Yes. So I guess I am bit of a girl in that respect (laughing).

Arthur tried to make sense of the lack of women in software engineering and he did so by suggesting that women have different orientation from men. That is, they wanted to work with people, not just do programming. However, when confronted with his own gender stereotype he maked a joke about himself as queer.

Wanja, 40, a system developer, confirmed a similar view in her firm, that men were associated with being technical competent and women were being associated with project management and user-related tasks:

But you are looked upon as being less technical when you are a woman. (…) I think you are more often asked to be a project manager, and you are more often asked to make demand specifications, and find out what kind of user interface, and user testing and all those kind of things. I think they tend to ask you that more often if you are a woman. But, we have two women who do technical stuff also. So, it's not a problem.

Wanja also said she would have wanted to participate in more programming projects. These general views of men and women, as having different skills, and perhaps complementary skills were sometimes used actively by the interviewees as an interpretive resource talking about their own practices as well. Arthur was recounting an episode of cross-gender team work, describing how it went:

It was fun to see that we [the men and women] did actually work a bit differently. They [the women] were very good at managing processes, to enhance people's competences, and make it into something. While we, the men, was more on the technical competence, and not always so good at communicating. So it was very exciting to work in teams like that, because I saw very clear differences, and saw that it was very useful. It was particularly one [woman] we used, who was very typical woman in the way she achieved results.

Thus, we see that particular skills in software engineering sometimes was associated with women, or rather a stereotypical view of women ("typical woman"), while technical competence was gendered masculine. Similarly, some also used gender as an interpretative resource to make sense of their *own* practices, like Agnes, when she talked about her work with developing a big IT-system for the justice administration:

And this is where the feminine qualities probably come in. I cannot understand that this [systems development] should not fit [women]. It is all about understanding an organization, to be able to systematize it, and make sketches on how to systematize it in a computer system, which is the actual part of what I do then.

Agnes was drawing upon a notion about 'feminine qualities' and using it as argument for why women (including herself) would be very fitting in software engineering, in systems development.

> *I think technology have many soft sides, really. Because, you are supposed to make systems that work for people. That is very important. And you need to systematize a lot, and I think women are good at that and very responsible. And good at talking with customers and grasping their needs, and being able to translate that to requirements in a system or in a model. And then I think women are really good project managers (…). So, I don't really get it [the lack of women in the field]. You don't have to be a technofreak to run projects like this.*

In addition to invoking the 'technofreak' stereotype (often found in literature to be a masculine stereotype) in computing, Agnes also described 'women' as good at communicating drawing on other stereotypes we recognize from the literature (Kirlidog et al., 2009). In addition, she also argued that women are 'responsible', 'good project managers' and 'able to grasp the needs of the user' which echoes arguments used in several Norwegian campaigns for recruiting women to computer science (see Lagesen, 2003).

To sum up so far, our interviewees provided rather similar accounts about their jobs, which required a mix of technical and social skills. Gender was enacted, but not often, by talking about women as being fitting for software engineering because of their 'feminine' qualities. These associations were primarily made in relation to the issue of the low number of women in computer science. Thus, this topic spurred productions of gender in terms of skills and orientations, mainly by drawing upon available discourses that has been surrounding this topic in Norway. Still, this also resembles Faulkner's (2000) finding of a difference between how people talk about gender and practices and what they actually do. Most interviewees in the Norwegian companies, men and women, preferred a mix of social and technical tasks, and expressed that making good, meaningful, useful systems was their main motivation.

Previous research has found that the particular 'masculinity' within computer science entail a strong fascination for technology and computers (see e.g. Hacker, 1989; Kleif & Faulkner, 2003; Wright, 1996). Was this the case among our Norwegian interviewees? Well, at first sight, yes. Some of the men interviewed did adhere to such an image, but in a retrospective way. For example, Walter, 31, a system consultant who had been programming since he was 7–8 years old, said:

> *Well, I have always been into computing. I am born and raised with that.*

Anders, 28, a system developer similarly stated*: I have always been fascinated by computers [since childhood]. (…) It was so exciting. And I have been fascinated by computers since then.*

Still, many said this fascination had developed in course of time and career. Anders reflected that having computing as a job was very different from having it as a hobby. Working with computers had also made him feel less need to play with computers. A few others said that their initial fascination for computers had changed and translated into a more professional interest. Preben, 27, a system developer, chose to study computer science because he had been “*in love with the technology*” but now he was more interested in business aspects:

> *That's perhaps the greatest satisfaction with the work setting as opposed to being a student. (...). [At work] you've to think about that people will have difficulties with this every day if you do something wrong. Then you've got to make – you've to really think and do things carefully and properly*

Thus, initial hobbyist fascination with computers had been moderated and changed by their professional practices, and resulted in the making of new positive associations to the application of technology, the user perspectives and the business relations.

How about the women software engineers? According to the scholarly literature we would expect women to mainly have shown an interest in the communication aspect of software engineering and less so in the technology or programming (Kirliedog et al., 2006; Yansen & Zukerfeld, 2014). True, it turned out that none of the women interviewees reflected on having been initially interested in computers. Many, though, had had positive associations to science and mathematics, and had considered IT as a probably ‘useful’ and relevant program for a future career. However, many said they had enjoyed programming when they got to learn it and had also programmed quite a lot in their early careers. Thus, while men and women clearly had somehow different paths in to software engineering, and we observed general gendered notions about skills and orientations in their profession, there were less gender differences in how they accounted for their approach, interest, professional orientations and skills as professional software engineers. The main goal was predominantly to be useful hybrids.

THE CALIFORNIAN SITE: GENDER BALANCE AND GENDERED DIVISION OF LABOR

Similarly to the Norwegian case, the accounts of our Californian interviewees about software engineering practices were strongly related to users and themselves as being a sort of mediators translating between programming and customers. Elaine, 50, a user designer, emphasized both the ability to grasp and analyze the context for the software and the needs of the customers as well as having enough technical knowledge, to understand all the aspects of the design process. Upon question of what is the most important skill in the job, she said:

> *An empathy with the user… Understanding what it is they`re trying to accomplish. Being able to appreciate what`s a good way of doing it and not such a good way of doing for them. Understanding what else they do and what would fit in well with that and what wouldn`t. (…) Just figure out all the things that might interact with one another. How are they going to program it? You have to understand well enough the constraints of programming, so that what you specification list is realistic and everything else that is going on.*

Even if Elaine did not program herself, she had no less than three degrees in computer science and said programming competence was crucial to 'push back' if challenged by those programming.

Among the Californian interviewees there were few, if any, who explicit made associations to gender, as opposed to the Norwegian interviewees. Communication, on the other hand, was also among emphasized as the most crucial activity in software engineering. Edward, 55, a senior computer engineer, was heading a team of software developers. He too stressed the importance of interpersonal and communication skills as the most significant feature of the work:

> *Well, you need to know some programming, obviously, stuff you can learn in school. But I think, most of the knowledge is, learning how to talk to people, interpersonal skills, so much of what we do depends on other people (…) Because, you know, we hire a lot of people right out of school, and they went to Stanford, or you know, MIT or something, so they learned all the programming skills. And they may or may not have right interpersonal skills. And that can be the killer. Because they may be the greatest programmer on the planet, but you end up having to isolate them if they can't talk to anybody, you know. You have to well, here, just do this, and keep them away from people.*

How to talk to people was a much more defining quality of a software engineers, than being able to program, according to Edward. He also enacted a negative figure that resembled the stereotypical hacker/nerd-type, but he did specifically gender it. Beth, 47, a software developer, labelled it as a rare 'golden person' this hybrid who could do both.

> *I think that's sort of like the golden person. Because having somebody who can do sort of the verbal explanation and has the technical depth, you often don't get those two things together.*

Also Beth did not assign a specific gender to such a person. Compared to the Norwegian interviewees there was a noticeable lack of the gendered discourse about skills. In fact, the only reference made to gender in these interviews was related to a difference between men and women with regard to work-life balances.

> *In general, I think women tend to value the work life balance more. (…) it's not that they don't wanna work, but they don't wanna work all weekend, and all nights and all these crazy hours. (…) that means they tend to gravitate away from jobs that are like that.*

Edward's arguments implicitly depict the characterization of the 'project mentality', a particular masculinity within software engineering argued by Murray (1993). Edward's assertion of men and women was based on an observation of other Silicon Valley companies rather than his own, though. His own company was in contrast, seen as particularly good at facilitating work-life balance and flexible working arrangements by our interviewees. Esther, 43, a product manager in the same company said:

> *[This] is the most flexible place I have ever worked. (…) It doesn't matter where you are, it doesn't matter how long I'm in the office, as long as I show up at the meetings that I need to be at. And (…) I could call in to most of them, and nobody would even ask a question. (…) The culture is really good about encouraging people to spend time with their families.*

Work-life balance was frequently brought up. We were told by our interviewees that in Silicon Valley there are many women choosing not to work while the children were in school. Some of our interviewees also talked about practical difficulties with getting childcare, and about social norms that is working against being a working mum. Ellinor, 36, a user designer, talked about how other mothers who did not work, created difficulties for arranging playdates because of her work situation:

> *So sometimes I invite the other kids over and then I'm like, "Oh can [my kid] come over sometime?" and they're like, "Well, I'm not really sure how that works because they have the after care." (…) So, it's a very odd fear of this unknown thing*

Apart from these, not many gender-related issues were brought up among the Californian interviewees. When we asked the women if they had been treated differently because they were women, they did not immediately find answers, but tried to reflect on it. Elaine, 48, a senior user designer responded:

> *Not that I know of, but you never know. You get treated as an individual, you're an individual, so you don`t know how you would've been treated were you in situations if you were a man?*

In fact, most of the Californian women interviewees expressed a great deal of uncertainty about what it meant to be a woman in their particular job. Erin, 37, a usability scientist, said:

> *I haven't experienced anything that I'd call sexism here. I've had older women tell me how easy it is for our generation. (…) But I haven't experienced anything from male colleagues. (…) I think it goes back a little bit to this culture – that is a very family-oriented company. (…) I never heard anything about, you know 'She's soft because she's woman. She can't make a decision' or something like that. I never heard anything like that.*

Erin referred to women stereotype as being 'soft' and unable to make decision, but said she never heard of or met such assertions about it in the company she worked in. Many of the women interviewees expressed doubts about gender discrimination and whether they had been subjected to it or not. This may of course be a reluctancy to see oneselves as as victims of larger social structures. However, Edward argued that there was another striking feature of software engineering more conspicuous than gender, namely ethnicity:

> *There are a number of women here, engineers, and there are a number of Indian, people from India (…) But, there are very few other groups of people represented. It is like very, very few black engineers, men or women. (…) Hispanics, almost none, never see them as engineers. (…)*

Thus, we see how another part of the Californian context is being enacted here, namely the context of ethnicity as a distinguishing factor in the recruitment to software engineering.

THE MALAYSIAN SITE: GENDER BALANCE AND GENDERED DIVISION OF LABOR

In the Malaysian companies we interviewed in, there were, as previously mentioned, a considerable more balanced number of men and women software engineers. How did the interviewees here describe the most important skills and practices? Kubtiah, 39, a senior analyst, provided the following account:

> *I am now doing a business requirement, and it comprises of getting requirements from the users … and I document the requirements, and get verification from the users, they verify whether it is right, whether their needs are what I documented. Then, I will talk to the technical people, to do the technical specification for the programs. Then they will do their testing, and after that they will run their testing, and they will pass to programs to me. Then, I'll do the personal testing. And if that is working well, I'll call the user to do the user test. Then they will eventually use the system. That is the process.*

As we see, her description closely resembles those we saw from our interviewees in the Norwegian and Californian site, except that communication was slightly less accentuated. Also, in terms of competences and skills considered to be required comparably more interviewees stressed their technical skills as their strength in the job, like Rohana, 30, a senior system analyst:

> *I think I'm good at finding solutions if there is a problem in the system. I'm a team member, so the 6… All of them are 6, and I'm the team leader, actually, in my team. So sometimes they've got problems, they don't know how to solve this problem. So I'm trying to solve their problem and provide a solution. Also … When we do the reporting, new customers, sometimes they don't know how to check the program. So I help them to check whether the program is correct or wrong. So, to display the correct output, I think.*

Communication was mentioned also here, but not stressed as much as in the two other sites. Neither was communication argued to be the most coveted skills as it was in the other sites. Actually, contact with customers was rather framed more as a potential problem. Radzi, 27, a system analyst said:

> *The most important problem is when it comes to misunderstanding between you and your client, your customers. When the customer requests you to do some report or some program, but you understand it in a different way. So, when you have finished the task, you come up with a thing – but this is not what they want. (...) Sometimes the users also change their minds. They want something different. So, that is sometimes a headache.*

Similarly, Rohana was not particularly enthusiastic about the customer communication part of her job:

> *I: So what do you dislike most about your job?*
>
> *Dislike? When your customer is ... It is very (...) so they actually don't know much about the computer. So, it's hard for you to teach them or support them to the system (...).*

Also here, the interviewees described their own practices and skills without making any associations to gender. How about different interest in technology and computers as we saw in the Norwegian site, and implicitly also referred in the Californian site? What had motivated our women interviewees to enter software engineering? Kamelia, 25, a system developer, said "*Well, basically because I love computers*". In fact, there were noticeable many more of the women interviewees who said that their main motivation was and had been an interest in and fascination for computers as such. Rubia, 34, a system analyst said: *Mainly I like computer science. (...) Because of the very logic .... I like technology. (...) it's more concrete*". Many also said they had previous experience with computers before entering university.

Also many of the men reported an early interest in computers, games or programming as a reason for entering computer science. Khalid, a 30-year old software developer said:

> *I was interested in games (...) So, I thought why not computer science? Maybe I can do some of my own games or whatever, so.*

Thus, the associations to hobbyist computing, was recognized, but not as strong. Still, there was a noticeable enthusiasm about computers among the Malaysian interviewees. Both men and women expressed an interest and fascination for computers. Still, there were no association made to any gendered stereotypes, like 'techno-freaks', hackers or the 'soft' or 'communicative' woman identified in the Norwegian site. This indicates that the educational setting in Malaysia had not been afflicted by the hacker- or 'geek mythology' present in many western settings (see Lagesen, 2008; Margolis & Fisher, 2002). We asked whether men and women performed different tasks in their company. Rubiah, 34, a system analyst and project manager, said:

> *Equal. Because in my company there are also programmers or analysts or system analysts, men and women. We are equal in that. (...) No difference. Only the task (laughing)*

Actually, our questions puzzled most interviewees. When we explained the situation of few women in computer science it caused surprise and amusement:

> *In our company there are so many women (laughing)* (Rubiah)

> *Oh, but here it's so many, yes (laughing)* (Radzi)

Women working with IT were taken for granted, and did not have to be 'explained'. Still, we did find a particular division of tasks between men and women. Kharizah, 42, an HR assistant manager, offered an observation that certain IT jobs, particularly programming and system analysis were done mainly by women while technical system engineering (hardware engineering) usually were done by men. What caused this division? Kharizah explained:

> *Normally they say that…in the programming job they need to do some very tedious tasks, right? Go out and do some very mixed tasks, need to be very concentrated... They [programmers] have to look for mistakes. Very small mistakes can affect the system in programming. So normally they say that; guys cannot…*

Kharizah referred to a discourse that projected particular qualities to women, which was the capacity of being careful, detail-oriented and patient. As we have shown above, this was markedly different to the stereotypical discourse about women's particular qualities in the Norwegian site.

How about gendered perceptions of men? According to our interviewees, being a man provided opportunities to more travels, to meet customers in distant places considered dangerous for women, like rural sites and other nearby countries like Indonesia. It also provided men with more space. Thus, there were impediments for women in terms of social norms of safety and appropriateness. Khalid, 30, a system developer told us:

> *(...) Considering our custom here, it is really not nice for a girl to go back at three o'clock in the morning. Especially if you are married, then a girl going back home late – the custom is just ... Not really nice. So ... especially when you have to go on excursions, outside.*

Such norms restricted women's movement in a way that spurred a gendered division of work. It was not considered appropriate or safe for women to travel alone. This was a barrier also pertaining to single women according to Kamelia, a 25-year woman programmer:

> *The guys, they can go to Indonesia, to our site there, to deploy our system. But for women, we have to stay there, because it's kind of dangerous there for us to go there. So it's like a barrier for us, as single women.*

These precautions and norms were seen as restricting women's careers. Rohana explained:

> *(...) if you go to the station, you will know more about the operation. (…) If you do system, you must know the operation. Otherwise you cannot meet the process correctly.*

Thus, despite the equal gender balance, there were cultural considerations that limited women's movement out of office and gave men more opportunities for communicating and interacting with customers. However, women were, considered more suitable to take care of programming and software development. Thus, the findings from Malaysia showed a reversed division of labor between men and women, compared to main findings in western literature.

DISCUSSION

In this chapter, I have investigated how software engineers account for their profession in three different sites and particularly how gender was enacted differently in these accounts. The aim was to identify potential differences in what I have conceptualized as the assemblages that constitute the professional practices in the sites we did interviews in. These assemblages appear as different configurations of practices, jobs, tasks, social relations, skills and competences in software engineering. How may we characterize the differences between these assemblages and how was gender enacted in these assemblages? Which *interferences* can be identified in the different assemblages?

First, an overall finding was that the accounts of practice and tasks were far less gendered than we had expected, considering the literature on gender in software engineering. By comparing the skills and tasks related to software engineering different and even juxtaposed associations to gender were demonstrated across the three sites. Most interviewees stressed the importance of hybrid skills resembling scholarly accounts of information systems development (e.g. Dahlbom & Mathiassen, 1997). There were some slight differences in emphasis though. What was designated communication tasks and skills were stressed as the most crucial feature of the work practices in the Norwegian and Californian accounts, while technical skills seemed to be more emphasized in the Malaysian accounts How may this be interpreted? In the Norwegian and Californian site this could be seen as a way to disassociate with the ridiculed image of the technically and narrowly absorbed stereotype. However, it may also be due to a genuine shift of perspective and orientation as result of a process of professionalization. This does of course not imply that the practices were different, but the way the practices were accounted for differed.

Gender was enacted and imbued with different meanings in these assemblages. In the Norwegian site, gender was made relevant in relation to software engineering in the constructions of women as having particular 'feminine' qualities that made them into better software engineers. Such argumentation could be interpreted as attempts to carve out a space for women in a men-dominated field. Moreover, such discourses have been made often in an Norwegian context, for example in campaigns to recruit more women to computer science (see Lagesen, 2003, 2011) and argued in literature (Kirliedog et al., 2009; Plant, 1996; Wajcman, 1991, 2004). Thus, such discourses appeared to interfere and affect the gender and software engineering assemblages in the Norwegian site. A few implicit associations made to 'techies' or 'nerds' weres made, but mainly as dismissals. However, gender was enacted in the women's accounts of sexism and perplexity women software engineers mainly met *outside* the profession itself, perhaps because of the unusual presence of women in these roles in the Norwegian setting, where the proportion of women have been much lower than both in California and Malaysia. Thus, one could argue that the low number of women in software engineering in itself represents an interference that spurred gender production in the Norwegian site.

In the Californian site there were fewer associations made to gender. In fact, the only association to gender made was about men and women's different choices or opportunities related to work-life balances. The frames for making choices was perceived as gendered, in the sense that women were subjected to different norms and practical difficulties regarding being 'working mums'. However, this concern may be depicted as actual challenges rather than be seen as producing gender. What spurred such concerns? Silicon Valley as a hotspot for start-up companies was mentioned as a barrier or interference, echoing the 'project mentality' described by Murray (1993) as a gendered mentality. Equal opportunities required a family-friendly policy in the companies, thus policy may be seen to interfere with the gendering of software engineering. Sexism and discrimination was mainly alleged to belonging to the past. However, ethnicity was mentioned and brought up as a stronger social distinction than gender. This may be seen as an interference of ethnicity that potentially made gender appear as a less relevant aspect of software engineering in the Californian assemblage, than for example in the Norwegian assemblage. Thus, we see accounts of gendered barriers in software engineering in the Californian site, but only to in relation to particular companies and work cultures.

In the Malaysian site the accounts of practices and skills included the same combination of technical understanding, capability of communication with peers and customers, and project management. However, communication and social skills were not so emphasized, as they were in the two other sites. Technical knowledge was more explicitly articulated as an inspiration for studying computer science and for doing the job. Interestingly, this technology focus did not include any associations to hackers or geeks, contrary to western contexts, including the Norwegian and Californian site although mainly visible by being dismissed. In the Malaysian site, computer science was portrayed as an exciting, 'new' technology. What interfered and contributed to such differences in the Malaysian accounts, compared with the Norwegian and Californian accounts? A brief overview of policy measures may be useful to interpret such difference. IT has in general been associated with modernity and progress in the Malaysian society and government has urged young people to study software engineering (Ng & Young, 1995; Ng & Mohamad, 1997).

Moreover, the large number of women in software engineering may also be seen as a result of an interference of ethnic policy that has particularly benefitted Malay women due to a traditional gender discourses about Malay men as under-achieving and lazy (Lagesen, 2005; Mellström, 2009). Also, and related, Malaysian government has attempted to remedy women's previously disadvantageous educational position through a state-sponsored, large-scale entry of women into mass education and industry (Lie & Lund, 1994; Ong, 1995; Yun, 1984). Even if many of these jobs have been low-wage jobs in electronic industry, they also paved way for women into higher positions and education within software engineering (Ng & Young, 1995).

The effect was a presence of women, which did not need to be 'explained', as was the case in the Norwegian assemblage (although less so in the Californian assemblage).

However, some clearly gendered barriers in the practice of software engineering was evident, where men had greater mobility than women. Wider social and cultural norms of what was appropriate for women were the main inference on this what role gender played in this assemblage. However, women were also associated positively to certain practices in software engineering, like programming. To sum up, the Malaysian interviewees enacted social gendered norms that on the one hand worked as barriers for women's careers restricting them to protected spaces, like work place offices and/or their homes. On the other hand, another ethnic-specific notion of (Malay) women made them into highly skilled programmers and software engineers and provided them with opportunities potentially transgressing the interference of traditional gendered positions in society.

CONCLUSION

Having found these differences in the assemblages and how they reflect rather different interferences, how may we then understand gender in relation to professional software engineering? The diversity of these assemblages and their site specific characteristics nuance and diversify the rather generalized accounts of men as predominantly occupied with technical tasks and having technical skills and women with people and having communication skills in the literature. Although, such stereotyped gender discourse was reflected in the Norwegian accounts but less so in the described work practices. In general, this study should serve as a caution against making context-independent claims about gendered characteristics of professional practices and approaches to skills in engineering.

Clearly, gender was part of very different assemblages (Haraway, 1994). These gender-and-software engineering assemblages were constituted by multiple and diverse interferences, and 'gender' was enacted in very different ways, took different shapes, and constituted the heterogeneity of these assemblages. The concept of interferences is suitable because what spurred the gender production in each of these assemblages was not derived from the practices, or the profession, or the work organizations as much as from various sources outside. The interferences took different forms: discourses, policies, research, norms, ethnicities, professionalization, numbers, expectations, and spatial concerns. Thus, there is no binary feminist policy to draw from this study. Rather, the study invites a cyborg feminist perspective (Haraway, 1987) which is a heterogeneous and less dichotomous view of gender politics. The cyborg metaphor reminds us that there are no pure categories and no fixed outcomes of policies. Thus, cyborg feminism invites a focus on the potentially ambiguous gains as well as strains of being a woman in software engineering. So, what lessons could be made from this study?

The findings in this chapter suggest that the hacker/geek culture of computing in western contexts may have been exaggerated in scholarship as a way to make sense of the low number of women in software engineering work, perhaps with an exception with respect to the recruitment of women students to the field in western countries. At least, based on the Norwegian assemblage one may ask if focusing on diversity rather than producing very generalized accounts of software engineering and gender in scholarship would rather contribute to less 'gendering' of the societal discourses on software engineering, and thus be more productive in achieving a better gender balance. Even if some of the 'positive' stereotypical discourses about women may appear as a potential advantage for women in software engineering, there is evidence that stereotypical images seldom are actually very effective, either to include or exclude women from software engineering.

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13. BETWEEN MODELS AND MACHINES

Theoretical Physics and Process Engineering

INTRODUCTION

The inclusion of Danish physicists' simulation modeling in this anthology on engineering practices and professionalism may not seem obvious. As I will argue, the choice is less arbitrary when one looks at the changing practices of physicists who are increasingly expected to mimic what Michael Davis in, 'Thinking Like an Engineer' describes as a *distinctive skill of engineers [which] is [to give] mathematical structure to practical problems* (1998:12). The physicists' work presents a case of non-engineers undertaking what approximates 'engineering'. Thus, the paper investigates 'engineering by other means' to bring into conversation how we consider the boundaries of engineering. While engineering is predominantly investigated from within its disciplinary boundaries, this chapter examines how non-engineers approach engineering from outside those boundaries. My core argument is that the 'applied tendency' within contemporary scientific practices creates a new domain of work that I call innovation science in which new forms of collaborations challenge how we consider the professional identities and practices of physicists and engineers. In the following I give a short account of the empirical setup, then I briefly portray the commercial reorientation of Danish science, which leads me to the theoretical framing of the physicists work into terms of Mode 2 science (Gibbons et al., 1994) and boundary-work (Gieryn, 1995).

This chapter investigates the simulation modeling conducted by a group of physicists who in 2011 to 2012 collaborated with a Danish rendering factory that turned waste from slaughter plants into protein meal for live stock fodder and raw fat for biodiesel. The collaboration was formed around the publicly supported project, "Energy-Efficient Control of Separation Processes," that included public university employed physicists, a consultancy that specialized in development and implementation of process control solutions and the limited liability company behind the rendering factory that was owned by a large group of Danish slaughter plants. The Renewal fund, which partly funded the project, operated under the Danish ministry of occupation to support: smaller companies in bringing new products faster to the market; improve Danish green tech production and consumption; and secure jobs in marginalized areas.

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The project's objective was to develop and implement new process control technology that would optimize the rendering factory's operation by decreasing energy consumption and increasing production yields. The physicists' job was to develop representative mathematical models (expression which structure and parameterization is made to represent salient features that define a target system or phenomenon) that simulated selected machine processes to provide more accurate knowledge of the machines' internal processes. This knowledge should in turn enable the consultancy to design and implement more accurate process control at the factory. On the basis that the primary responsibility for the control project and most of the work that converted the physicists' results into technological applications was performed by the consultancy they stand for the engineering counterpart against whom the physicists' modeling is compared in the following analysis. The empirical material was collected through a multi-sited ethnography that I conducted throughout the two-year project on an independent grant from my university. Onwards I refer to the collaboration as "the control project".

Science for Commercial Innovation

While the physicists' involvement in the control project may seem unconventional, it reflects the way in which social expectations of scientific work in contemporary Denmark have turned toward industrial application. A decade before the control project received its grant the then minister of science, technology and development, Helge Sander, launched the initiative, "From research to receipt," that since the turn of the millennium has been the mantra for Danish science. Since 2001, a steady stream of reforms have turned Danish universities into economically autonomous institutions and exchanged universities' collegial self-governing system of elected leaders with executive boards consisting primarily of external members from industry (Carney, 2006). The 'bibliometric research indicator' – a Danish ranking system for international journals – became a counting system to measure, compare and distribute public funds between universities based on their publication scores (Bruun Jensen, 2011). Another example was the installment of 'recruitment panels' consisting of industry leaders whose advices and interests became part of Danish higher education's recurring accreditation.

In 2006 the Danish government further intensified its focus on "quality", "competition", and fewer but higher profile strategic long-term research projects. While steadily increasing Denmark's public investment in research from 0.8% to 1% of GDP from 2006 to 2010, an important component of the new game plan was to increase the share of competition distributed funds to reach more than 50% of the total public support for science no later than by 2010 (Finansministeriet, 2006). Whilst increasing competition, the complimentary part of the plan was to increase the share of private investment in research and development to become twice that of public investments. Decreasing funding for basic science and more funding for public-private partnerships, meant that researchers, like the theoretical physicists in the control project, had to make themselves attractive to industrial partners in order to secure funding. As a result, the success criteria for publicly funded research came to center on commercial application within industry for the most direct benefit to the Danish economy.

Changing Knowledge Boundaries

Based on analyses of the structural characteristics of European scientific activities, authors of an influential study concluded that contemporary science followed a trend whereby it was valued for its impact in society. Gibbons and colleagues (1994) coined the new tendency 'Mode 2 knowledge production' and characterized it as a historical paradigm shift away from a disciplinary university based research where the overarching aim had been to acquire "reliable knowledge" about nature and society – the so-called 'Mode 1' knowledge production. Mode 2 instead presented a shift towards "socially robust knowledge" produced by heterogeneous groups of actors organized around problem contexts. In the view of its authors mode 2 included the following characteristics:

- Knowledge is increasingly produced in contexts of application (that is, all science is to some extent "applied" science).
- Science is increasingly trans-disciplinary; that is, it draws on and integrates empirical and theoretical elements from a variety of fields.
- Knowledge is generated in a wider variety of sites than ever before, not just universities and industry, but also in research centers, consultancies, and think tanks.
- Participants in science have grown more aware of the social implications and assumptions of their work (that is, they have become more "reflexive"), just as the public has grown more conscious of the ways in which science and technology affect their interests and values (Jasanoff, 2007).

As a consequence of Mode 2's emergence, Gibbons and colleagues noted that the assessment method by which science was evaluated had to be reconsidered to encounter a new and more interwoven fabric of science that besides intellectual merit had to address questions about the purpose of its research, the marketability of its results, and the social accountability of its enterprise. In other words, Mode 2 represented a science that, in opposition to that imagined by Robert K. Merton (1942/1973), Vannevar Bush (1945) and Michael Polanyi (1962/2000), became answerable to society rather than detached from it. With Mode 2, the values and ethos of science became more akin to what we understand as engineering.

The performance criteria of Mode 2 knowledge production adhere to a different ideal than Mode 1. By making the performance criteria about how knowledge production impacts society rather than how it adheres to scientific disciplines' internal criteria, Mode 2 brings into question disciplinary distinctions such as that between physics and engineering. The Mode 2 version of expertise, "transdisciplinarity," sets itself apart from 'inter-' and 'multi-' disciplinarities by not originating from traditional academic disciplines (Novotny et al., 2001). Instead, transdisciplinarity is understood to emerge around context specific problem solving with new compositions of knowledge and knowhow that have practical utility. This leads us to the question of the place and role of disciplinary training in our understanding of contemporary knowledge work? Does the Mode 2 trend dissolve the boundaries between established fields such as physics and engineering, or is Mode 2 rather to be seen as a policy ideal, which practical implementations require further investigation and perhaps reconceptualization to understand?

Thomas F. Gieryn's seminal work (1995) on boundary-work has shown how the on-going demarcation of boundaries between fields of knowledge often involves high stakes for its participants. Founded on the philosophical difficulty of making rigorous distinctions between science and non-science, Gieryn (1983) defined boundary-work as the, "attribution of selected characteristics to [an] institution of science (i.e., to its practitioners, methods, stock of knowledge, values and work organization) for purposes of constructing a social boundary that distinguishes some intellectual activities as [outside that boundary]." Although many prominent sociologists and philosophers of science such as Robert K. Merton and Karl Popper sought for a criterion by which science, in a stable, transhistorical and reliable way, could be distinguished from other forms of knowledge making, so far no one has succeeded. When applied to physics and engineering, boundary-work provides us with an entry for looking at how disciplinary boundaries are being drawn, redrawn and negotiated in the context of Mode 2 knowledge production: What does it mean for the content of work, the professional identities of its participants and for our understanding of the success criteria by which we evaluate the merits of such work? The repositioning of physics within the context of technological innovation thus challenges not only our understanding of physics but also how we come to think about other professional practices with whom they collaborate. How can we for instance think of the roles and purposes of engineering – the domain that is usually associated with technology development?

Because Mode 2's success criteria are meant to apply to all knowledge productions, they can be seen to challenge the internal criteria of traditional disciplines' self-assessment. Mode 2's reframing of knowledge work is thereby likely to affect the demarcation dynamics performed from within multiple disciplines when they perform work under similar performance criteria to those of other disciplines. The physicists' involvement in the control project presented a form of boundary-work that was driven by the physicists' necessity to re-justify their value to society within a funding regime which success criteria emphasized research's commercial application and social impact. In effect the physicists' simulation modeling of rendering machinery provides us with a gaze into how physicists attempted to demarcate their 'science' as a field of knowledge and methods that applied to industrial innovation and thereby measured up against 'non scientific' performance criteria that would usually be associated more with those of engineering.

This gets us to the core problem of the chapter: how can we characterize the physicists' work in the control project and what is its relationship to engineering, pure science (Mode 1) and Mode 2 knowledge production? At one and the same time the physicists' work resembled Mode 2 knowledge production but their disciplinary heritage also challenged the Mode 2 assumption of transdisciplinary expertise – formed around practical problem solving rather than through disciplining traditions of academic fields. Would it in other words be reasonable to assume that what makes good physics will also, when organized around industrial problem solving, make good engineering, or are we dealing with a potentially new category of knowledge production with its own unique success criteria as I have argued elsewhere (Juhl, 2016)?

The purpose of this chapter is to examine how the physicists' representative work applied to the engineering domain of industrial process control in order to characterize the nature of their work and its implications for how we think of science in the context of commercial innovation and its boundary-work with engineering. The analysis of the physicists' simulation modeling is structured around how their decisions measured up with Mode 2 production criteria and the engineering ethos of applicability and practical usefulness (Davis, 1998).

THE CONTEXT OF APPLICATION: THE CONTROL PROJECT

The rendering factory whose production machinery was the subject of the theoretical physicists' modeling was located near the little town, Løsning, along highway E45 in the Mid Jutland region of Denmark. The owner of the factory, Daka Bio-industries, processes pig carcasses and other animal waste products from slaughter plants. At Daka they referred to the animal waste products as "product". The rendering plant functioned as a service that received and disposed of waste products from the 19 slaughter plants that owned Daka. Demand from new German and Chinese buyers had pushed up the prices for the better quality waste products, which to Daka meant restricted control over the quality of the product they received.

To get an idea of the production issues that the control project was intended to deal with, I will briefly go through the production's setup. The raw "product" entered the factory with trucks where it was received in large containers dedicated to soft, hard or mixed product compositions. The composition of raw product referred to its quality. 'Hard' was bones which contained most protein and fat whereas soft mostly consisted of entrails and had the highest percentage of water. From the containers, the product was transported, mixed, minced, grinded, heated, pressed and scraped as preparation for the following separation processes.

First, the coagulator, which worked as a long slightly elevated transportation screw that doubled as a steam driven heat exchanger, pulled up product while heating and liquidizing its fat content. The product then entered the press machine where mechanical pressure separated liquid from solid product. The liquid was pumped to three-phase decanters in which it got separated into liquid raw fat, wastewater and a

Figure 1. The Løsning factory seen from the parking lot (picture by author, 2011)

Figure 2. Top end of the coagulator with the press beneath (picture by author, 2011)

heavier solution containing solids. The liquid raw fat was collected in tanks where it was stored for distribution. The solution with solids were mixed back into the solid product from the press. This mixture was sent to the disc dryers where remaining water was evaporated until the dry mass was hot enough to enter the mill where it could be filled into big backs for transportation.

This paper focuses on the initial modeling of the disc dryer machine. Disc dryers work as large cylindrical tanks in which large discs with shovels rotate slowly to mix, move and exchange heat from steam power to evaporate water from the product. Depending on the product's water content the drying could take more than 4 hours before the dried product reached the 111 degrees C before food regulations allowed the discharge outlet to open. The temperature of the output product typically continued to increase before it cooled and the outlet closed once it decreased to 112 degrees C.

Figure 3. View into a disc dryer (picture by Author, 2011)

The two main separation principles at the factory were mechanical separation and heating/evaporation. Mechanical separation was preferred and most energy-efficient but was highly sensitive to process variations. For efficient operation the coagulator's heating of the product was considered imperative for the ability of the press to perform effective mechanical separation. Fat that failed to liquidize and get squeezed out with the run off fluid would end up in the protein meal where it represented less value. Ineffective mechanical separation would also require more water to be evaporated in the disc dryers, which put greater strain on the production capacity and overall energy consumption.

The factory's main production challenge was to remove the approximately 60 % water in the raw product. The energy consumption, of which heating and evaporation were the primary factors, amounted to roughly half of the factory's total running costs. Another issue related to the extraction of raw fat, which represented the greatest market value – about 5 times that of the protein meal. The control project's objective was to 'improve process quality' – or in other words to increase the effectiveness of separation and thus reduce the amount of fat in the protein meal while minimizing the water to be evaporated from the disc dryers – all of which would increase production yields.

The disc dryers were especially prone to oscillations in their output temperature. Their efficiency was particularly important to the factory because of their highly energy demanding evaporation of water. With temperature oscillations exceeding 130 degrees Celsius, the dryers were prone to excessive energy consumption from overheating the product. A model that could predict the disc dryer's internal processes would be of value to more effectively mitigate their temperature oscillations and thereby contribute to reducing the factory's overall running costs.

The control project's ambition was to develop model-based control products for a wide range of applications in process industry. CORE, the project holding consultancy, was responsible for the coordination of, and information exchange within, the control project and for turning the physicists' results into operational solutions that produced positive effects within the production. CORE began as a spinout from the Niels Bohr Institute at Copenhagen University where its CEO was a professor in physics of complex systems. The CEO together with an employee who had a master's degree in engineering thus formed a hybrid competency profile that combined physics and engineering. The consultancy occupied a central role in the control project. Not only were they responsible for setting up the collaboration and securing the Renewal fund grant, but they also tied together the work of all the project partners. The consultancy detailed the overall plan for when the respective participants should deliver what and supported the participants' ability to deliver by collecting, analyzing and distributing information within the collaboration.

In the project's initial phase, the consultancy used its expertise in process analysis to collaborate with the factory on delivering a complete process description in which the available information on the production processes was collected. These descriptions were passed on to the physicists who used them to develop representative mathematical models of selected machine processes. By running their models on production data, the physicists produced plots of the machine process that served as inputs for the consultancy's development of new control solutions in the following phase of the project.

Although the physicists were swift to deliver preliminary plots from their premature models, they continued to refine their models for better accuracy far beyond the scheduled time. The final and most accurate models were first available to the control project at a late stage where most of the new control solutions had already been developed.

Because of the control project's time constraints, the consultancy went with the less accurate machine process plots from the initial models as inputs for choosing control parameter set-values in their new control solutions. For the coagulator, the physicists' model revealed a temperature plateau in raw product's movement along the coagulator's length axis that accounted for the fat content's phase transition from solid to liquid. Simulation plots of different raw product compositions illustrated how the coagulator's output temperatures related to different time intervals where the raw product's temperature would be beyond a given process-critical value. Guided by the physicists' simulation model plots, the consultancy configured variable output

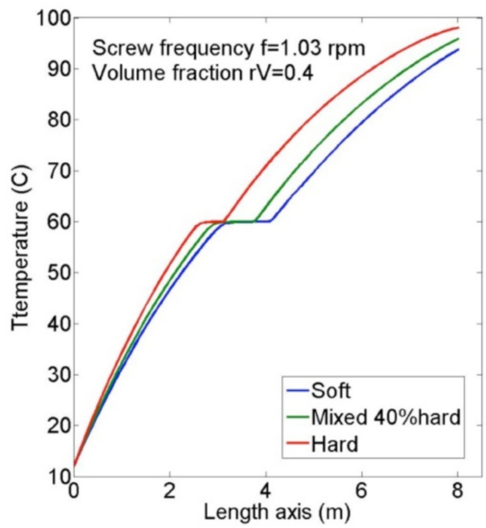

Figure 4. Plot of the coagulator's simulated temperature development for Soft, Mixed and Hard raw product compositions (plot from Zhang et al., 2012)

temperature set values that accommodated different fat concentrations in order to avoid under- or over-heating the product to improve energy efficiency and improved subsequent separation quality.

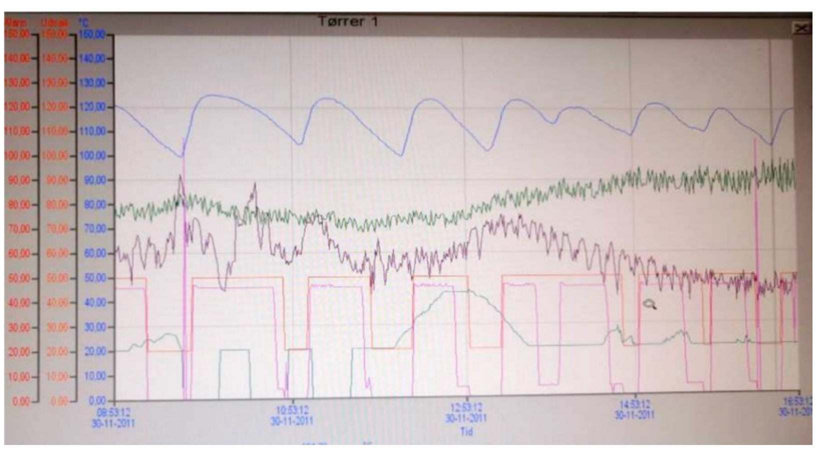

Figure 5. Screen shot of disc dryer test. The upper curvy line is the output temperature and shows the effect of an early manual test of the new control scheme conducted by the author in November 2011. Left-hand side shows the control data. Right-hand side shows the new operation scheme (picture by author, 2011)

Besides expertise in process analysis the consultancy held a patent on their adaptive control model that formed the basis for the operational implementation of the control project's solutions. The adaptive controller's advantage was to adapt its machine steering based on tendencies in the machines' performance history. According to CORE, their adaptive control method improved mitigation of process oscillations – a well-known problem with typical Proportional-Integral-Derivative (PID) controllers because their fast operation cycles often 'over steer' slowly responding machine process.

CORE's approach to process control was to go for 'simplicity' – identify the most critical process parameter and the most effective input parameter to control it. Process analysis on basis of the relationship between the two was used to mitigate erratic machine behavior. For the disc dryer, CORE's hypothesis was that the timing between the open state of the dryer's outlet and the temperature buildup inside the machine were responsible for producing the temperature oscillations. The idea came from the way that the phase relationship between the direction of an acting force and that of the moving mass is understood to produce Eigen frequencies in mechanical systems. By shortening the outlet's open times by closing them once the output temperature's maximum had been reached, this hypothesis was tested to good effect as oscillations' amplitude was significantly reduced as can be seen in Figure 5. In contrast the physicists' models appropriated the complexity of the production machinery in order to produce more accurate predictions. But to utilize that accuracy, more accurate production data was needed.

The control project was part of the final stage of a major modernization whereby the Løsning factory's production was fully automated and its operational interfaces reorganized. The automation enabled the factory's staff called 'operators' who were responsible for the production's daily operation to monitor and operate the machinery from their newly built shared control room. Pre-automation, the operators were located close to their respective machinery within the four separate production domains: raw product reception; heating and pressing; drying; and the mill. Communication issues between the domains and the prospect of running the production with one less operator were central to make new the control room.

While managers and operators expressed satisfaction with the new organization of work, there still persisted disagreements about how to run the individual machine processes most efficiently. Because the machine interiors presented harsh environments for sensors there existed only production data referring to process inputs and outputs. Interpretations of the internal machine dynamics responsible for the processing of product were therefore difficult to juxtapose with data or other forms of reliable evidence. The spread in operators' training and educational backgrounds was in part responsible for their diverging views on the production. Most operators were craftsmen by training and many also had a Bachelor in Technology Management and Marine Engineering. Newly hired operators went through 3 months of apprenticeship with an experienced operator from whom they learned his or her tricks of the trade. Some operators used their fingers to assess the quality of product by squeezing it gently to feel its consistency. Others looked for threshold values of specific production data parameters, which they used as indicators for obtaining the intended process quality. According to the operators, the complicated and unpredictable nature of the production environment meant that 10 years of dedication to one operational domain was required to become a "good" operator.

The culture of operation was about 'keeping the production running' by preventing hiccups – or worse, dealing with production stalls. Differences in the ways of controlling the machinery meant that the factory depended on human operators, their individual experiences, and their operational priorities – all of which generated variations in production that were difficult to manage. Because of the operators' highly specialized skills and the individualistic working culture, the management had few effective means for streamlining their practices. Striving for one 'optimal' scheme of operation to which all would commit, was an idea that was first introduced with the control project. The introduction of theoretical physics presented an entirely new vantage point for understanding the production that exchanged practical experience with universal science.

The factory's management was separated into daily operation and strategic operations. Daily operation managers had backgrounds similar to those of the operators and were responsible for overall production planning and repair scheduling whereas most of the strategic management were trained engineers and were responsible for the planning of larger renovation- and modernization projects like the factory's involvement in the control project. The management's vision for the factory was to reach a degree of automation where the factory would only need "one green and one red button" – to start up and to shut down the entire production. The aim was to reach a state of automation that would make the production independent of human operators. New 'intelligent control' should take the operators out of the equation and thus remove 'the human error' from the production.

The control project's role within that scheme was to introduce two innovations that should realize this vision for the factory. One was the physicists' 'prediction models' that would provide new knowledge about machine processes and how they were expected to behave under given parameter changes. Prediction models were simplified simulations run off the physicists' representative mathematical models. The other innovation was the consultancy's adaptive controllers that would operationalize the prediction models for tighter and more 'intelligent' process control to achieve greater production efficiency. When installing the new machine controls, it became apparent to the consultancy that the precision of the coagulator's output temperature measurement was paramount to improving the separation quality of the successive production processes.

An important part of the project's operationalization was to implement a new temperature sensor contraption that read its temperature directly of the run off fluid from the press. Together with another initiative that used the raw product grinders' current measurement to estimate raw product composition before it entered the coagulator, the control project requested new standards for accuracy and utility in the factory's data production that better matched those of the physicists' modeling. At the final stage of the project, the physicists sought to validate their models, but despite the initiatives to produce better data, the physicists never achieved to source data of sufficient quality to validate their models. Instead priority was given to 'proof of concept' tests that over the course of a few days generated uninterrupted data on the operation of the new control solutions that could be compared to regular data in order to document the operational merits of the control project's results in terms of improvements in fat separation and energy efficiency.

The main assumptions underlying the factory's cost reduction strategy are worth to note. Firstly, the factory's management saw the production's dependence on human operators as a weakness. They assumed that displacing agency away from the human operators and onto new control technology would increase economic yields. Secondly, even though the operators had significantly more experience with the day-to-day operation of the production, the factory's management considered the theoretical physicists' knowledge more credible for making decisions on uniform optimization of the production. Experimental automated artificial intelligence based on machine learning and universal physics was preferred over human intelligence and practical experience. Despite the epistemic authority placed on the physicists' models, resources were prioritized toward documenting their operational impacts as part of new control solutions rather than the data validation that would offer scientific credibility.

To the production environment with its highly specialized operators who were used to work autonomously guided by their idiosyncrasies, the control project presented knowledge and technology that offered the management more centralized control. The advantage for the factory's management was not in itself the ultimate accuracy, with which the physicists built prediction models, nor the sophistication of the intelligence programmed into the adaptive controllers, but how these combined reallocated power towards centralized control.

The political implications of the automation at the Løsning factory play into long-lasting discussions surrounding the politics of artifacts (Winner, 1980) and reflect how scientific and technological changes reinforce the existing social structure (Noble, 1979). Interestingly, the operators at the Løsning factory did not officially object to the automation and those who did speak, accepted it as a "necessity for maintaining occupation within the industry". The vision of progress held by managers and operators can be seen to reflect a sociotechnical imaginary (Jasanoff & Kim, 2009, 2015), in which the belief in the vision of 'centralized technological control' depreciated manual labor and practical skills. The management's success criterion for the modernization of the factory can be coined as to achieve the best possible 'effectiveness of control' – that is to acquire the fewest possible elements with which to control the most possible elements of the production.

APPLYING PHYSICS TO THE DISC DRYER

The intention with the theoretical physicists' construction of mathematical models was to attain new insights about the internal dynamics of production machinery that were not accessible through production data. The group of theoretical physicists worked more than 100 miles from the rendering factory at the University of Southern Denmark. The predominant literature on simulation modeling focuses on scientific applications where simulation models are understood to generate knowledge in situations where experimental data is sparse or inaccessible (Johnson, 2006) by connecting data with theory (Sismondo, 1999). The context of the control project differed from that of science by using modeling as a means for improving production processes. To the control project, mathematical modeling offered the affordance of connecting the particular conditions of the factory, to which only sparse production data referred, with the universal principles of theoretical physics.

In the following analysis I seek to characterize the physicists' modeling by focusing on how their decision-making reveals preference patterns and tacit hierarchies of concern in the ways in which they chose to represent the disc dryer machine. The purpose of the analysis is to explicate the ends, which the physicists' work tactility supported and compare them to those entailed by engineering and Mode 2 science in order to draw out where the physicists' work overlapped and where it differed from both.

The focus of the following analysis is the initial modeling, where the physicists made the decisions that were most central for the design of their representative models. First, I will briefly go through the model construction's successive stages to give an overview of the representative modeling in the control project. The initial and most fundamental challenge was to decide what theoretical physics first principles that would account for the most important machine processes. *The question is that there can be several processes that are important* [Theoretical physicists]. On the one hand the physicists had to identify the most important machine processes while on the other hand they also needed to ascertain the first principles with which these processes were best represented through analytic mathematics.

The analytical model would then be refined and transformed into a numerical model that the physicists could parameterize to fit the machinery's construction. Once reaching this stage, the physicists could run their model on production data and produce simulations that would generate data on how the model predicted the machine to behave. Plots of simulated machine behavior could then to be shared with the other control project participants. However for the physicists to know that they "caught" the most important processes, they needed to validate their models against production data. *It could be that there were other processes – and it could also be that some of these processes weren't that important to model* [Theoretical physicists]. Data validation ultimately meant that the physicists relied on the rendering factory to produce data of sufficient quality that would be compatible with the parameterizations of their models.

Step 1: From Data to Preliminary Model

There is a profound visual dimension to how physicists and engineers (Juhl & Lindegaard, 2013) work and think. Niels Bohr's depiction of the atom is an abstraction that amplifies particular ideal features of atoms' structure by deliberately misrepresenting how physicists understand atoms' physical manifestations. Representational accuracy is not to be mistaken with theoretical significance in scientists' visual work. The following analyzes how theoretical physicists translated empirical information into a preliminary structure upon which an analytical model was eventually based.

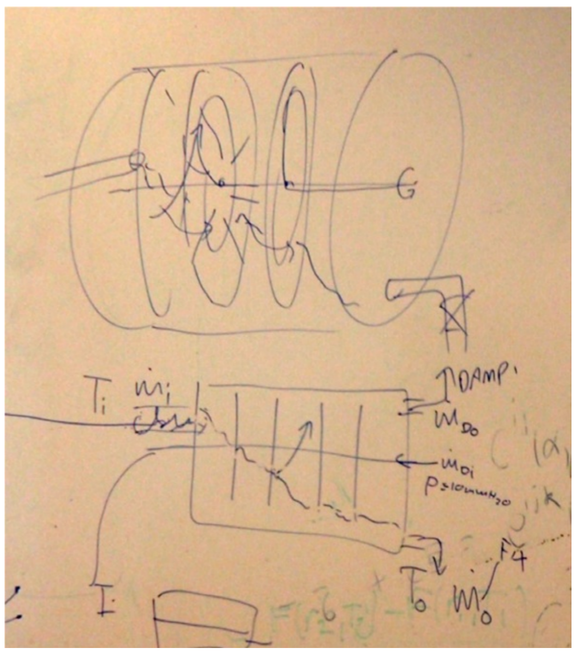

Figure 6. 3D and 2D principle of the dryer as representations took shape during the meeting (picture by author at modelling meeting, 2011)

To begin the first meeting, the physicists made two sketches of the disc dryer machine on the whiteboard (see Figure 6) that visualized: mechanical features; physical processes; and production data parameters. The upper sketch illustrates a crude three-dimensional representation of the machine. The physicists understood the internal physical construction of the dryer to be a big cavity containing: rotating discs; product inlet; outlet; and the internal distribution of product. Beneath the 3D sketch, we see a two dimensional sketch where the round discs are represented with lines separating the dryer's interior into discrete volumes. The physicists attached to this illustration operational parameters known from the machine's operation at the factory. These included: mass flow and temperatures of the product entering and leaving the disc-dryer; the electrical current used to rotate the discs; temperature; and mass of the water vapor leaving the machine. The white board illustrations functioned as the physicists' preliminary 'ad hoc' model in which they juxtaposed what they knew about the disc dryer.

> *This is probably also the picture that we have gotten on the board now; that the disc dryer actually combines a tank where it is fed with some mass in on the one side, and then some discs that rotate, but rotate without helping to press the material through.* (Physicist)

The sketches were the results of a translation whereby the physicists organized the available information on the dryer into a crude model that expressed how they understood the machine's construction. Information about the dryer figured as discrete visual components that gave content to the machine sketches, which overall construction in turn provided context and purpose to each component. The models give us an early glimpse of how the physicists worked to understand the disc dryer. Inhabiting the ad hoc model with components, drawing on information from the dryer, were the initial steps in constructing what to analysts of science and engineering are know as 'working objects' or 'proxies' that function as 'stand ins' for the machine and thus form small hybrid matter-sign footbridges to narrow the metaphysical gap between the physicists' model and the machine (Latour, 1999). While on the one hand making the disc dryer machine more present to the physicists, the referential relationship was highly distorted and deformed between the sketches and the machine they represented. The analytical affordance was that the physicists' understanding of the dryer's construction converted into a preliminary model structure. At this initial stage of modeling the physicists' construction of proxies represented analytic utility paralleling that which engineers are understood to seek: to give the 'problem' the structure necessary for mathematics to be applied at a later stage (Davis, 1998, 12).

Step 2: Extrapolation from the Known to the Unknown

The physicists' definition of what physical functions they should represent was central for the way that the later model would approximate the dryer machine's internal processes. Because no data on the disc dryer's internal processes existed, the physicists used their model's structure to qualify their interpretation of the most relevant physical functions of the dryer. Most of the equipment was originally manufactured for food production. Machine drawings were generally available but there were no data detailing the dynamics of the dryers' processes. This is where the physicists began to produce new knowledge about the dryer's interior processes by extrapolating from what was known about the machine.

> *Why are they there?* a physicist asked about the dryer's rotating discs to which the reply sounded: *To conduct heat. Not to transport* – another physicist immediately replied.

The analytical scope of the conversation moved from the machine components to the physical functions that the physicists assumed the components to convey. The discs' potential function of transporting mass through the machine was voted down in favor of exchanging heat. Before the physicists could apply mathematics to the model, they needed to decide what physical functions they believed would adequately capture the machine's processes and thus provide reference to their corresponding mathematical functions. This presented a second type of translation in the physicists' representational practice: The exchange of one set of proxies for physical construction and components with another set of proxies for the machine's presumed physical functions.

> *The most important is probably the heat conduction, as you say for the discs, and then that there comes mass in does that mass has to get out again, so isn't it most likely that [heat conduction] is the most important function, […] could one then not just replace that with an effective heat conduction?* (Physicist)

With the turn to the dryer's physical functions, the physicists traded away the model's structural resemblance with the target machine for instead to gain resemblance with how theoretical physics describes ideal processes. The epistemic affordances was to move the model further away from the uncertainty imposed by the sparse production data and instead move the model closer to the widely conceived certainty of universal physical law. The physicists in the control project thereby expressed epistemic normativity that was committed to, and preferred, deductive theory articulation rather than strictly data based inductive reasoning. Instead of conditioning their modeling by the available data, the physicists suggested the dryer to work based on how they believed it should work. Basing their model's referents on physical law, the physicists chose to design their model from the outset of how theory could account for its physical function. In return, the vantage point of theoretical physics only offered a finite range of possible governing principles for the physicists to consider.

For heat exchange, the first principles of thermodynamics dictate that energy, in the form of heat, flows from one medium to another due to their relative temperature difference. On the assumption that the total amount of energy must remain the same, the physicists wrote up equilibrium equations that connected the disc-dryers' energy inputs with its energy outputs. The functional delineation of the dryer thereby cleared the path for translating the model into mathematics. Physical functions were exchanged with their corresponding mathematical functions.

Step 3: Adapting to Application

In order to simulate the dryers' oscillating output temperature the physicists' model needed to include additional ideal processes to that of heat transfer. The physicists' intuition led them to also investigate the dryers' internal mass-flow. Despite the physicists' decision that the internal discs' primary function was heat transfer, they still needed to account for the mass flow through the dryer in order to explain the oscillations in the dryer's output temperature.

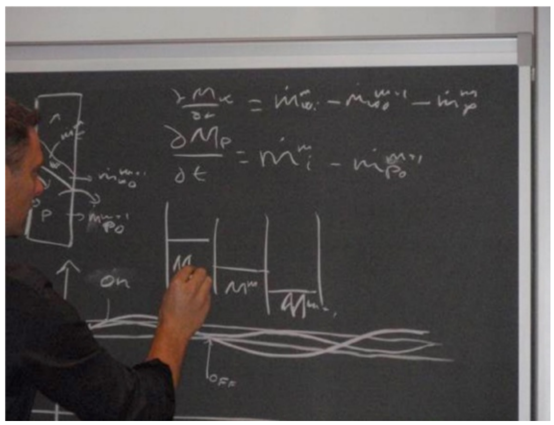

Figure 7. Modeller at the blackboard describing the mass transportation in the disc dryer (picture by Author, 2011)

Figure 7 shows another depiction of the disc-dryer at the following modeling meeting. While the previous meeting centered on the dryers' internal heat exchange this meeting focused on mass flow. The illustration in Figure 7 depicts the dryer's internal discs as spatial dividers separating the dryer's body into discrete volumes with discrete masses. The new interpretation of the discs' function entailed an additional function. The physicists now saw the discs as conditioning the dryer's internal mass-flow. Not necessarily actively propelling mass forward but possibly passively restricting it. The question they were trying to answer was what kind of mass transportation this passive restriction produced. Theoretical physics provided the solution space; it had to be either diffusion or a flow process.

> *Why do you call it diffusion? It's flow isn't it? – the first derivative… …But basically you are now just formulating continuity equations, you don't have to talk about the mechanism behind it.* (Physicist)

Theoretical physics gave the physicists two distinct options. Either the mass moved through the machine in a uniform stream from input to output as a "flow process". Or, the mass moved simultaneously in all directions between the discrete volumes as a "diffusion process". Mathematically, this meant either a 1st order derivative for flow distribution, or a 2nd order derivative for diffusion distribution.

Although heat conduction was identified as the primary function of the dryer, heat conduction alone could not adequately account for how the dryer worked. While physical law describes regularities in idealized physical phenomena, the operation of complex physical phenomena, like industrial production machinery, do not reproduce these idealized regularities in a straightforward and observable way. Combining in one model the mathematical representation of the dryer's heat exchange with that of its mass transportation, the physicists designed the model's mathematical structure to better approximate the complexity of the dryer's combined internal processes as seen in Figure 8.

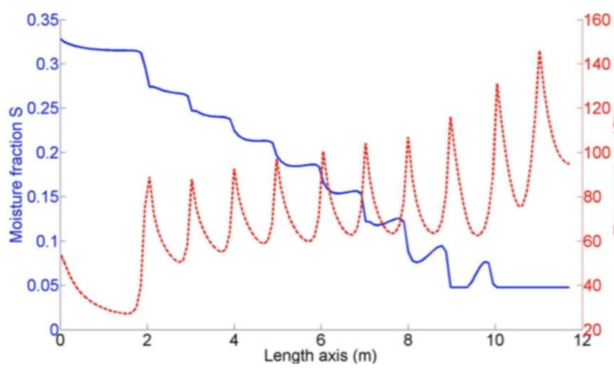

Figure 8. Plot from the physicists' dryer model showing the dynamic relationship between the product's output temperature (ascending sawtooth line) and water content (descending curvy line) in reference to the dryer's length axis at time 18.8 hours

The Factory Uptake of the Simulation

Although the physicists saw their early simulation plots as preliminary and crude approximations, the factory's management and the consultancy acted upon them as facts. Instead of questioning the physicists' interpretation of the production, the management authorized their knowledge by choosing their representations of the production processes over those known to the operators. The management thereby achieved to rely on only one unanimous representation guiding their imagination and decision-making on how to optimize the production. No one besides the physicists themselves had the necessary insight to their knowledge production in order to be critical of the representations it produced. The other participants in the control project were more interested in building on the physicists' epistemic authority than in questioning it. Notwithstanding the epistemic accuracy of the physicists' machine models, their sociopolitical performance in the control project was to form a shared technoscientific imagination by which the collaborative efforts were coordinated toward shared goals.

Over the course of the control project, proof of concept tests were conducted on the coagulator and the disc dryer. They showed a 25% increase the dryer's efficiency, 10% less water content in product entering the dryer and 1% increase in fat production yield. The tests were carefully orchestrated and included many other elements than the physicists' inputs, which makes it impossible to assess the exact extent to which improvements could be ascribed to the simulation models. In February 2012, right about the termination of the control project, Daka Bio-industries formed an alliance with the international SARIA group.

THEORY ARTICULATION AND THE PROBLEM OF VALIDATION

Disciplinary training builds preference patterns, which can be observed through how professionals make decisions. The theoretical physicists began their modeling by making assumptions about the target system. Their assumptions instigated with the physical construction of the disc dryer. Then they translated their representation of the dryer's physical construction into how that construction made possible the physical functions that would explain the machine's internal processes. The physicists' commitment to let theoretical physics govern the structure of their model had consequences for the model's applicability to its intended target environment. By letting theoretical physics define the parameterization of the model, its data-validation placed additional demands onto the quality and quantity of the production data against which the model should be tested.

Taking departure in first principles, the physicists chose to model how the machine processes in their professional opinion ought to be. Instead of working from a pragmatic outset in the available production data, the physicists chose to base their modeling on idealized theory. While this made it possible to accurately trace their model's mathematical structure back to theoretical physics, the way in which this was done, placed new demands on the conditions under which data was to be produced for testing the model's accuracy. As a result, the rendering factory could not accommodate these higher demands that were placed on its data production. The physicists' professional preferences made them imagine ideal conditions where there were anything but ideal conditions.

The irony was that the principal reason for the physicists' involvement in the control project was the lack of complete and reliable data. The physicists knew of laboratory data production, but not of the constraints that the rendering factory imposed on its data production. Their actions let their professional commitment to the physics underlying the machine govern how they organized their model and the data needed for its validation.

The epistemological directionality of the physicists' representational practice brought the model from an outset in partial and risky knowledge about the dryer's physical construction and operational behavior and into what to the physicists was a comfortable, secure and well-known territory of theoretical physics. The notion directionality was introduced by Gary Downey (2013) to investigate the 'material normativities' of engineers inherent to technological development and creating as well as the 'epistimological normativies' expressed by the physicists representative modelling. By choosing first to engage with production data after they had defined their model's theoretical structure, the physicists constructed a void between their model's parameterization and the available production data. The physicists demonstrated a preference for theory articulation rather than ensuring their model's compatibility with its intended target conditions – including the available production data. Although several initiatives were commenced at the factory to comply with the data needs of the physicists' work, their models were never data-validated.

SIMULATING KNOWLEDGE IN THE CONTEXT OF APPLICATION

While Mode 2's success criteria are about social impact by means of producing knowledge for practical applications, the application-orientation's implications for the production of knowledge are not well understood. In the following I discuss how the theoretical physicists' simulation modeling made theory apply to the particularities of the rendering factory and what it meant for the knowledge being produced.

Theoretical physics is available in the form of first principles and theorems that apply to universal phenomena through abstract entities. Theoretical physics do not in a straightforward way apply to the everyday conditions of an industrial production like the rendering factory. According to Cartwright (1983, 55): *the laws of physics lie", because they "do not tell what the objects in their domain do*. In other words, the laws of physics only hold under certain conditions where objects are constrained to reproduce the regularities we know as physical law. Laboratory experiments are made to create such conditions. Thus the regularities we know as physical law are reproduced under conditions that are different from those present at the factory. The model construction was an attempt to bridge this divide by aligning the conditions under which physical laws are understood to be true with the particular production conditions at the rendering factory.

In contrast to the scientific method that constrains physical objects to produce the order predicted by theory, the physicists had to manipulate theoretical first principles in order to make them refer to the local production conditions at the rendering factory. This manipulation is what is typically referred to as representative mathematical modeling. In philosophy of science this knowledge practice is explained as theory articulation (Winsberg, 1999). Although the theoretical physicists' work fits this description in that it articulated first principles to represent internal processes of production machinery, the philosophical literature on simulation modeling has little to say about the implication of the intended industrial application for the physicists' work.

Because the objective of the physicists' work was to give theoretical structure to the industrial application, their work resembled some traits of engineering. However, as discussed, the physicists' modeling expressed preference for theory articulation over a more pragmatic inductive approach. Their work therefore constitutes a special case of professional demarcation that operates between well-established categories known to the existing literature. The physicists deployed theoretical physics as means for practical ends. As my analysis of the physicists' representational practice illustrated, this made it difficult for the involved stakeholders to determine what the performance criteria for the physicists' models were. While the physicists reproduced their disciplinary inherited epistemic preference for theoretical traceability, the factory and the consultancy instead sought operational compatibility. The assumptions through which the physicists sought to make accurate representations of the production placed demands onto the factory's data production that were neither technically nor economically feasible to accommodate.

THEORETICAL PHYSICS IN THE CONTEXT OF COMMERCIAL APPLICATION

The physicists' participation in the control project was based on the expectation that their models would provide knowledge that would be useful for improving process control. In the light of the commercial reorientation of science in Denmark, the control project and the physicists' within it serves as an example of how contemporary Danish science, technology and innovation politics were implemented in practice. By being organized around, and applied to, practical problem solving within the rendering factory's production, the physicists' participation in the control project resembled Mode 2 knowledge production. However, when we examine the physicists' modeling we find evidence of their disciplinary heritage being expressed in their preference for theory articulation, theoretical traceability, and representational accuracy. The physicists' modeling sought to hinge what knowledge they had of the machine to universal theory, which made them choose referents to theory over those to the machine and its operational environment. The physicists strove for the most theoretically accurate explanation of the dryer's function whereas the consultancy sought the most effective control under the given conditions.

This is where Michael Davis' simple 'knowledge versus usefulness' distinction gets challenged when attempting to characterize the physicists' work. While the consultancy is a good example of someone who prioritized usefulness, the physicists would seem to prioritize knowledge, as their published paper on the dryer model had no mention of practical usefulness. But the knowledge they built was adapted in order to apply to the specific production machinery rather than having universal applicability – as would be the territory of 'pure' or 'Mode 1' theoretical physics. They did not build theory but applied it to say something specific about the production machinery with the intention of generating useful knowledge to the control project despite their knowledge oriented framing in their publications.

While the physicists failed to validate their models and therefore could not be certain that they 'caught the right processes' their efforts were still seen as useful to the control project by the consultancy. Although the models fell short with regards to physics' internal assessment criteria such had no consequences for the models' usefulness to the control project. The fact that the control project used the physicists' models, despite their inability to validate them, shows that the 'usefulness to process control' -criterion required significantly less representational accuracy and certainty than that aimed for by the physicists. The domain of work in which the physicists' representational modeling formed part, was engineering of process control that operated after a unique set of success criteria that were based on 'operational usefulness' and 'impact on production yields.'

At the outset of the control project, the relationship between the physicists, the consultancy, and the rendering factory had not yet developed mutual understanding of the operational requirements of the other participants. Throughout the two years of collaboration, the development of a base of collaborative experience was expressed in the physicists' increased interest for the rendering factory's operational environment. Simultaneously, the consultancy began to realize how the physicists operated while new measures for tighter and more accurate data production were implemented at the factory.

We can see the collaboration at its outset to consist of the operational production environment and theoretical physics as discrete social worlds (Clarke & Star, 2008). Towards the end of the project, the consultancy's mediation between the two had affected the practices and identities of all three by producing a new domain in which theoretical physics, the production environment, and its adaptive process control converged around shared success criteria that became increasingly common basis for their interaction.

CONCLUSION: SCIENCE; INNOVATION AND THE NEW ROLE OF ENGINEERING

The control project participants operated after different success criteria. While the engineering of process control sought simplicity and testability in their assessment of problems and design of solutions, the physicists sought the best possible accuracy in their representative modeling. The control project's operational objective can be seen as to distribute and coordinate dedicated roles among its participants in such a way that their different success criteria would come together around the same application. The physicists were supposed to provide new and more detailed insights to the internal processes of the production equipment but shot far above what the other participants considered 'accurate enough' for their purposes since they were more interested in the resulting production effects rather than the accuracy per se. This tension between how the control project's participants understood the relationship between their respective roles and the projects' overall success criteria represented the project's most central challenge.

In the light of the political initiative 'from research to receipt', the tension within the control project can be seen as part of the political intentions surrounding the reorientation of Danish science towards commercial application. A large study of the outcomes of the commercial reorientation of Danish science concluded that while the commercialization of science entailed larger costs than its economic payoff, the real benefits resided in stronger relationships between academic researchers and private industry. The tension between academic and private participants' perceived success criteria could in this light be seen as an important potential that requires co-adaption between the science, the scientists, the engineers, the industry and the problems around which they organize their collaboration.

Science's move towards innovative applications not only marks changes within scientific practices, but also corresponding responses within industry that attempt to find ways to harness from their academic collaborators. Brought to bear on engineering, the control project enables us to rethink its purposes and processes. The consultancy's function was to operate as a 'broker' that ensured the connection between the scientific production and the site of its intended application. By translating the factory into problems that were accessible for the scientists to work with and implementing the results of the scientists' work into the factory environment and thereby acquiring 'usefulness', the consultancy in effect performed a two-way maneuver. This translational role appeared to be not only central for the coordination within the control project but also vital for the results it produced. In the awakening of new modes of production between academic intuitions and private industry, engineers' skillsets make them uniquely adapt to play a key role in ensuring the development of mutually beneficiary relationships.

In this role, rather than applying science or giving mathematical structure to practical problems, engineering becomes the mediating practice that transforms and connects the conditions under which scientific knowledge is produced with the conditions under which industrial problems and their solutions can come together. Shifting from 'application' to 'connection' displaces demands on engineering competencies from application of scientific methods to their critical assessment. The relationship between the knowledge production and the requirements of its intended application becomes the principal problem for engineers to solve. The required skillset thus changes from the ability to apply mathematics to the ability to translate practical problems into conceptual problems that enable other forms of knowledge making to contribute effectively to the solution. In this view, engineers need new skills that enable them to assess and evaluate the great verity of means, ends and practices of the partners with whom they collaborate. For engineering education, this emphasizes the demand for ambidextrous engineers who have the necessary methodological means to critically assess and direct the work of academic scientists. In order to populate this role successfully, engineers' ability to extract the practical essence of problem contexts and the potential solution space must effectively be translated into an organizational skill that ensures ingenious coordination between scientific and non-scientific efforts.

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PART 4

LESSONS LEARNED

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14. THE POLITICS OF ENGINEERING PROFESSIONALISM AND EDUCATION

INTRODUCTION

In this concluding chapter, the authors discuss the implications of the findings presented in the chapters of the book. The contributions will be framed within the most important current debates on engineering professional work and the reform of engineering education.

The studies presented in the book have approached engineering in work and education by looking at the practices of engineers: professional engineers, engineering students, and engineering educators. The focus has been on what are characteristics of 'the sayings and doings in engineering'. All contributions refer in one way or another to the fundamental issues of the fields of Engineering Studies and Engineering Education: How is the engineering profession produced? What counts as an engineer? What do engineers do? The result is a rich and contrasting collection of thick descriptions of activities within engineering education and professional work on how engineers make sense of what they do. All chapters challenge the monolithic view of engineering as objectively applied science and show the conflicts and contradictions within engineering educational institutions and engineering workplaces as well as how these two sites of engineering interact.

CURRENT DEBATES ABOUT ENGINEERING

To broaden the scope of the contributions we first discuss two issues of engineering that are prominent in current debates. First, the portraying of engineers as the heroes of technology aligned with the idea of technology as the key force for societal change and development. Second, the continued controversy around educational reforms in engineering aimed at including substantive attention to contemporary societal issues and how they challenge classic views in engineering.

The first debate refers to the role of technology in contemporary societies where e.g. some expectations support that new waves of technical innovation will solve resource shortages and reduce if not reverse the impacts of climate change. These expectations extend to include technologies ability to address challenges related to populations growing older in some parts of the world and increasing in others as well as the impacts of urbanization and increased population density. While technical elements obviously are fundamental parts of possible solutions to some of these

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problems, robust solutions demand a broader engagement with social impacts and influences. The visions centered in technology and innovation must be contrasted critically with a broadening agenda for social innovation, social responsibility and justice, new forms of engagement with entrepreneurship, user involvement as well as the sustainability transition agenda that all together raise issues about new forms of economic and political order concerning commodity exchange and infrastructures.

The contributions in this book show how technical analysis and quantitative modelling still dominate engineering, and thus many engineers and applied scientists pursue the ideal of the representative models or the optimal analytical tools to solve problems. At the same time, many contributions show how this core set of disciplines and approaches proves limited when directed at social and sustainability challenges. Because traditional and instrumental approaches remain pervasive, respondses to social challenges that in non-traditional ways actually brings design back into engineering as an approach to working with wicked problems are met with skepticism and marginalization by engineering institutions.

The second debate relates to the content and learning practices of engineering education. The dominant paradigm is to focus on science based analytical tools with an instrumental perspective of knowledge transfer and provision. To challenge this dominance, several reform initiatives have emerged focusing on pedagogy and learning, like Active Learning in Engineering (ALE), the Conceive-Design-Innovate-Operate initiative (CDIO), and Problem and Project Based Learning (PBL). Several of these pedagogic initiatives also include a more active engagement with authentic, real world, wicked problems in interaction with companies, local communities and local governments.

The contributions of this book have explored how challenging the traditional focus on analytical tools brings to the front a number of issues related to engineering, which are otherwise invisible, such as questions of identity, social context, users of technology, learning practices and the many non-technical aspects of the content of engineering work.

MAIN FINDINGS

To discuss the questions presented in the introduction and the current debates we have divided the discussion of the main findings of the book's chapters in the following five sections:

1. in the first section we discuss the social and environmental challenges facing engineering practice in education as well as in professional work situations and how these are included, perceived and translated within engineering schools and companies;
2. which is followed by a discussion on how institutional frames at different levels govern how the objects of engineering are perceived and how engineering practice is being performed and transformed;

3. which leads us to a discussion of engineers' identity formation resulting not only from educational frames, but also from societal norms and the goals of the engineering and technologies being applied;
4. then we move on to discussing the experiences and achievements arrived at by focusing on engineering practices and compare these with the lessons from earlier contributions coming out of the practice turn in engineering studies;
5. the final section wraps up by reflecting on the cross cutting findings concerning controversies about the knowledge base of engineering, the interrelation of education and professional work, and some ways to respond to the societal challenges facing the engineering profession.

Our approach will be to focus on the main contributions of each chapter to the themes above and their consequences. We will discuss these contributions, point out the main lessons learned and suggest further lines of inquiry.

SOCIAL CHALLENGES AND ENGINEERING RESPONSES

In terms of social challenges facing engineering practices, the contributions of this book concentrate on three areas:

a. responses to environmental and energy issues, followed by a broadened scope of sustainability,
b. responses to engineering as design with increased focus on use practices and users of technology, and
c. responses to demands for engagement with community development and entrepreneurship.

In line with the position taken in the introduction to the book, we do not divide the response strategies, the codes of meaning and the translations into those visible in educational practices and those visible in professional work practices. We approach education and professional work as parallel appearances of eventually similar response patterns. The specific practices observed do not reflect a demand or transfer of competence from professional practices to education (as anticipated when talking about a 'gap') but reflect how the different sites of the engineering profession reflect knowledge building in response to changes in society and the environment at large. This has implications for how engineering as a profession evolves and how changes, new concerns and work practices are taken up.

Valderrama, Brodersen and Jørgensen analyze in detail how environment and energy were included in the research and teaching at two engineering universities in Denmark. Their analysis shows how the translation into the existing institutional and educational structure was controversial in both institutions with respect to the difficulties in positioning these new challenges into instrumental topics of teaching engineering. On the organizational dimension, broader societal and ecological topics did survive as independent units but were subsumed into existing departments.

In one institution, the environmental concern was taken over by a tradition of sanitary engineering adopting mainly an end-of-pipe approach while other aspects were taken up in a production management and product development context. The energy challenge was translated into technology improvements and priorities while the broader climate aspects were more or less lost. At the other institution, there were efforts to consider the environment as a social problem through the articulation of solutions that involve rethinking planning, governance and production practices. In both cases, however, the environment remained at the margins of most of the existing disciplines that continue to dominate engineering disciplinary teaching. This can be summarized by the following conclusion:

> *… over a period of several decades environment and energy challenges have been taken up in engineering educations through the building of new engineering tools and metrics. … In this process, the broader, analytical takes on these challenges through ecology and social science approaches have been marginalized. … the same happening in the responses to climate challenges and sustainability. Solving open ended problems resulting from taking actions in sustainable transformation mostly is represented in strategic rhetoric while only few, dedicated and specialized educational program and even fewer courses have been established.* (Chapter 4)

Petersen and Buch explore how users were addressed based on new approaches in the design of vehicles at a car manufacturing company. The starting point for the study was the challenge of bringing users and use practices into focus in engineering design. Their analysis reveals how users, and the engineers and designers that study them, are still marginal to the company's core business and organization with its focus on car manufacturing. Through the translation of car use into a focus on user experience and transport journey comfort and the development of methodological as well as design concepts that gain foothold in the traditional car engineering company, the group manages to make themselves a necessary addition to the companies design activities.

> *One of these new approaches to engineering is the user-oriented approach to engineering design, which (in the version discussed here) focuses on holistic and socio-technical dimensions. The overall aim is the same (developing successful technological solutions), but the way successful is understood differs (useful rather than functional), as does the means of reaching it (based on user needs rather than technological requirements).* (Chapter 9)

Brodersen and Lindegaard describe how inputs coming from studying users are subordinated practices focusing on the governance of product concepts and production process at a medical device company. Though gaining new insights in use practices was core to the company's design activities continuously, the contact with users became more structured to manage relations and inputs and focus on those aspects of product improvement and testing that lay within the company's established pathway for conceptual changes.

> *The studied company is organized in such a way that the User Experts 'sell' their insights about users to other Departments within the company. It is also worth noting that it is only a very small part of the user insight the User Experts persist, the Marketing, and the R&D departments are interested in. The fact that the Marketing Department is responsible of exploring potential markets and products, the Industrial Designers creates the idea around (idea, shape etc.) the products, the Engineers develop (functionality of) the products and the User Experts carry out user-tests, reflects a very traditional distribution of work.* (Chapter 10)

In the study of a wicked engineering design context related to the development of a manipulator, Henriksen studies how this object of engineering plays a part as an actant with agency of its own and without being clearly defined either as a problem to be solved or as a solution with defined specifications. Its indeterminate status as an object of engineering work challenges the perception of both methodologies and specifications take their starting point in defined and controllable problems and demonstrate the basic wickedness of typical engineering design objects in the making.

> *… we can conclude that the manipulator is an object, an actant, an artefact, a piece of equipment, a tool. … But it was much more than that. It was also a process and it was part of a world. Tools and actants are part of a world … and they are also constitutive of these worlds; it follows that they are all necessary in order to understand the process that made the manipulator. For the engineer and for engineering this is very important. Constructing a device like the manipulator is not just about designing, calculating and drawing as part of engineering practice. It is just as much about disclosing a new world, conceptualising, translating in the mangle.* (Chapter 11)

Lagesen's analysis contributes to a nuanced discussion on how software design/production is configured in three countries to attend different perceived and even participating contexts and uses of information technology with their customers. The focus in the article is on gender issues in the context of information technology and programming, with special attention to the design challenge of combining the ordering and structural aspects of coding with the social context of use. The study reveals demands for broader skill sets among IT programmers and rejects the idea of a traditional hard-core coding culture that is commonly associated with a specific nerdish and masculine professional culture.

> *The diversity of these assemblages and their site specific characteristics nuance and diversify the rather generalized accounts of men as predominantly occupied with technical tasks and women with people, reflected nevertheless*

> *in the stereotyped gender discourse in the Norwegian accounts but less reflected in the described work practices.* (Chapter 12)

Canney explores how universities are increasingly offering curricular and extracurricular activities to support students willing to get involved in development issues, with development being one of the master narratives of engineering as technical expertise at the service of humanity. This relates to a broader trend within engineering educations to focus on entrepreneurship and the multiple dimensions of business and social involvement paralleling user involvement in design. However, Canney eloquently dissects how this cultivated path of professional realization is not attended by companies and workplaces that still demand engineers concentrate their efforts around their main expertise: to deliver technical solutions through the application of quantitative methods in a large organization. In Canney's analysis, electing a career path that takes up development challenges is equated, with the choice of a difficult and often marginal career path, e.g. in specialized development organizations or consultancies, and that even in some situations may result in abandoning engineering altogether. What in educational settings has been taken up as a challenge and met with study options and new forms of learning does not simply equate with how most companies still perceive and govern engineering professional work.

> *… these cases provide examples of what would happen if educational systems continue to strive to create more holistic engineers, but the professional engineering culture remains as it is currently. … Therefore, is Learning Through Service selling a lie to engineering students? … The question remains; how do the engineers with these skills fit into the current professional engineering environment? … LTS is an educational approach which fosters the skills and perspectives that are being called for by many engineering professional societies. These skills are technical and professional, as well as attitudinal dispositions that can help educate a holistic engineer. … there is a need for professional models to change, striving to accept and further develop the holistic engineers being fostered within modern engineering education.* (Chapter 7)

Kamstrup analyses how the CDIO approach (a specific concept for educational reform) is taken up in a learning environment at an engineering school. The spirit of CDIO initiatives is to bring back a robust design approach into the education of engineers as well as to emphasize the importance of implementation and operation as engineering fields of competence. By robust design we mean a process that focuses on the understanding of a problem, conceiving different solutions, selecting the best one, unfolding the overall and detailed design and assessing how it could be implemented and operated. However, Kamstrup's analysis of the actual practices reveal how the spirit of CDIO is transformed or even betrayed by the evaluation structures at the institution becoming in the end a number of disembodied criteria the students have to satisfy. This is not least resulting from the fact that this is what the students are exposed to in any other engineering course at the university, especially those that offer training in some disciplinary knowledge from engineering science. While teachers still might emphasize the visionary aspects of the CDIO concept, the institutional frames reproduce the codes of meaning circulating within the disciplines carrying the core of engineering methods and problem solving. Engineering students focus on the actual codes and demands in their practices even if they acknowledge the broader intentions.

> *There is a sharp contrast between the specified standards of CDIO and the various enactments of CDIO at the universities. … The administration argues that implementing CDIO is a way to make sure that the students learn what they need to learn, but that goal is difficult to evaluate when CDIO is enacted in multiple ways. … the enactments of CDIO show that students and instructors have different agendas in some of the classes where the instructors try to connect the workplace and education using CDIO while the students are trying to make sense of their education and focus on that, rather than their future workplace. Ironically, when the students recognize this entanglement in their project concerned with building a house, it seems that the instructors obscure this entanglement by only assessing the written report and not the constructed house. This argument points to the conclusion that CDIO may have potential in entangling workplace practices with educational practices, but there must be a certain common understanding of when this is ideal to do.* (Chapter 6)

This resembles the experiences from the study of Tonso, which demonstrate that students' responses to the dominant codes of meaning in instrumental science teaching results in difficulties in working with open-ended design tasks of clients from external companies.

The findings from the two settings that frame and behold engineering professionalism in education and work practice demonstrate a varied set of responses. Some of the described initiatives stimulate new perspectives for the profession while others preserved existing codes of meaning and enforce a translation of the societal challenges into already existing patterns of technical and instrumental solution spaces. Neither the educational setting nor the business and work settings seem to define the frontiers of change in general. Resistance to change is prevalent in both settings as well. Rather different patterns and interpretations of the challenges are presented in each realm, demarcating divergent approaches to the development of engineering professionalism.

The contributions that address social challenges so far reveal how engineers and engineering educators are conceived of as independent when one examines closely their sayings and doings – or to moderate the stark dichotomy, are divided into a spectrum of positions between two poles. On the one side we find those actors making sizable cognitive and practical efforts to address social challenges with all the complexities that entails are embracing the wickedness and sociotechnical character of those challenges. These actors consequently support a broadening of engineering education and work practices to include perspectives and methods from design and social sciences as well as critical perspectives from natural sciences as expressed in e.g. ecology. On the other side we find those engineers and educators that are sensitive to the challenges, but that argue for a need to translate these into technically framed solutions and methods. This implies translating the challenges into problems that are solvable technically, eventually resulting in eliminating certain key aspects of the challenge or leaving those aspects to other professions and disciplines.

Common patterns reveal the codes of meaning circulating within educational institutions and companies when societal challenges are translated into dominant professional conceptions or are subordinated and reduced to marginal add-ons. The first is demonstrated when the early warnings of the environmental and energy challenges from the 1960s onwards were translated into revisions of the sanitary, the production management, and the planning disciplines of engineering in a way that was dependent on these fields' existing representations within engineering disciplines. The translations have shown successful in transforming existing engineering fields and specializations to provide new methods, technologies and managerial/governance approaches to reduce pollution and provide new, efficient and even renewable energy technologies.

Actually, the challenge persisted and resurfaced in the more dramatic challenge of climate change. How the engineering profession and knowledge institutions should respond to this new face of the challenge remain a battlefield, with the continued dominance of 'technical solutions' within existing codes of meaning. The efforts to open up the field of engineering knowledge, training and practices are still subordinate to what, in the eyes of many engineers, are 'real' technical solutions, a core technical knowledge base, and business opportunities related to these defined in strict technical and commodity terms.

As societies progress further into the Anthropocene, engineering will be confronted with balancing two different pathways for development. Either the engineering profession take professional responsibility for sustainability as a complex, sociotechnical challenge and expands radically what is considered to be engineering's domain, or the profession continues along the path established during the 20th century focusing on a variety of narrow technical aspects of the challenge that may contribute to change, but with no overall guidance. The latter deferring to other professional groups and actors in society the less measurable and more wicked aspects of the sustainability challenge and the institutional and social transformations emerging.

In many respects and intertwined with the conclusion on sustainability that encompass the dimensions of social coherence, equality, and impact of technology on modern everyday life the societal challenges will not diminish in the years to come. On the contrary they will extend the value conflicts in engineering both in educational work settings as well as in societal interactions at large on the role of engineering. Consequently, engineering can not refrain from reflecting this challenge.

While periodic resistance among engineering institutions can be observed as shown in the studies, the penetrating influences identified in the fields of engineering design, entrepreneurship, sustainable transformation and development concerning equality and social change. At the same time the studies presented show that the social worlds organized around existing products and business priorities frame how new perspectives and competencies impact these fields. Product and service development engage with users through design and new engineering methods, but only by placing these as manageable objects in the format of ‘user experiences’, ‘user testing’, ‘community services’ and ‘entrepreneurial activities’. The controversies about the role of engineering uncover the different positions and point to the need for further work and engagement in the attempts to change fundamental aspects of engineering.

INSTITUTIONAL FRAMES AND ENGINEERING

In the former section, we focused on the responses to social challenges as they appear and manifest in the practices of engineering education and work. Our guiding perspective was how the existing disciplines and business concepts played a role in the codes of meaning and resulted in specific translations of the challenges. We touched upon how departmental structures and how manufacturing and product concepts influenced the codes of meaning at play. In this section, we focus on how institutional frames influence practices, extending the discussion of translation by bringing in a broader set of issues that relate to aspects of professional and institutional policies beyond the application of knowledge.

The institutional frames and their impact become visible in the chapters by Akera and Tang, which point to the role of engineering education as a provider of formal skills in scales relevant to the economy. But they go further to highlight how the governance of these institutions itself becomes a policy driver and a core part of the education and research institutions’ positioning.

> *This description of the major policy directions … point to a shifting policy landscape, one characterized by increasingly neoliberal modes of governance. This includes increasing market competition; a strong focus on workforce generation; attempts to rationalize higher education administration through new measures of accountability; and various efforts to align higher education and research to state and national agendas. … While it remains tempting to measure neoliberalism through its specific characteristics, what is again more fundamental is the underlying penetration of market values and practices into the institution of public higher education. … This being said, different political economic orientations ensured that the relative balance between economic interests and other social policy objectives, such as educational access, social mobility, and the basic structure of the workforce remained a central feature in conversations spanning both time and space. … Europe seems to be capitalizing on the strengths of its secondary education system to elevate*

> *their former, typically, five-year undergraduate degree programs into a set of terminal master's degrees. … the Master's degree remains an orphaned degree in the United States, in that it is often considered a stepping stone for those pursuing a PhD …* (Chapter 2)

The ability of educational programs to address and act upon to social challenges is only one of several dimensions that institutions have to respond to. Others are the ability to attract qualified staff, to maintain contact with industry and public service providers, to attract research funding and to maintain a reputation for quality. Neoliberal governance reform has multiplied the number of external relations of engineering institutions now also including accreditation boards and increased contact with employers to ensure the relevance of their programs. This has resulted in different strategies and positions.

> *… entrepreneurialism had permeated deeply into Danish educational institutions … This kind of conduct stands at the very heart of the Bologna Process, whose intent has been to strengthen European institutions of higher education by fostering competition across institutions, promoting greater specialization, and encouraging institutional change and innovation. … What is perhaps most striking about our findings is the extent to which the schools have chosen complementary strategies, not only with regards to the kinds of degree programs offered, or their strategic posture with regards to research, but with respect to intellectual commitments vis-à-vis things such as disciplinary retrenchment and interdisciplinary programs. From the standpoint of innovation, diverse approaches are more likely to produce diverse outcomes.* (Chapter 3)

Especially the formalization of research competences and the attraction of research funding have resulted in institutional frames emphasizing research and innovation activities as the basis for science-based teaching at many institutions. Despite a rhetorical focus on giving high priority to teaching competences and the need for social skills, these arguments play a secondary role in recruitment practices. The neoliberal reform has emphasized the competition between institutions and their orientation towards – in an economic perspective – markets for engineering training and technical science research. This has resulted in differentiation strategies on one hand, but also in a degree of conformity concerning the orientation towards research funding, which has an indirect impact on priorities given to science disciplines and what has been called the academic drift in engineering education (Christensen, 2012). Whether the focus on accreditation has supported or weakened the disciplinary orientation is still an open question, while it definitely has introduced a new governance regime.

Another important, but also contradictory impact of institutional efficiency measures is related to evaluations of and exams on students' learning priorities as reported by Harder, where the exam sets the stage for students' learning despite the official project based learning principles and its focus on solving wicked problems. It is not a new discovery that exams impact what is learned as e.g. discussed and documented in studies of engineering education. What appears contradictory is that these forms of control prevail and survive pedagogical, educational and accreditation reforms demonstrating the importance of institutional routines.

In the work practices of engineering and as a challenge to changing these work practices, the structure of manufacturing, product qualities and markets and consultancies function as a rather conservative barrier. The past dependency of established mass markets and the established business models play an important part when recruiting new engineers. Due to the need for businesses to adapt to new demands, experimentation is happening in e.g. front-end innovation activities and in specialized consultancies. Often these are contained within specific departments as in the case of Petersen and Buch's study of user-experience based design in an automobile company, or the new approaches have to demonstrate their worth by translating these into known practices within established product domains as shown by Brodersen and Lindegaard. This explains the difficulties and specific forms that design engineering has to take on to be able to fit the dominant organizational (institutionalized) structures. Also in Canney's study the traditional job constitution in companies seems to limit or even exclude the new types of competencies and visions coming out of educational institutions improving their students the ability to work in relation to social actors. The problem is not uni-directional, as in the cases presented by Lagesen on the information technology business. Though companies ask for coding competences as one important basic competence they prefer to employ computing engineers that are able to cope with the customer needs and are able to translate between the social and the coding sphere.

Whether the institutional and business perspectives are all rational and productive – even in an economic sense – is questionable. While the focus on quantification and the use of models are a core part of engineering practices, studies of the demand for and use of models tend to show a different picture. As the study by Juhl demonstrates, models are often not directly related to or even productive for – in this case – the optimization of industrial production, but modelling runs as a parallel activity stream within the company's application environment, supporting the vision of optimization and governance of technology and production. This perspective contrasts the linear view that science and theoretical models are the tools and preconditions for optimization and innovation.

> *Although the professional identities of engineers and physicists appear to be converging at the level of applying natural science to technical challenges in society, it neither means that physicists and engineers make similar choices nor that they produce similar results. … While scientific matters-of-fact based reasoning arguably has transformed engineering from being a technical craft into becoming a respectable scientific discipline, the presented case*

> *also serves to illustrate some of the pitfalls that potentially accompany this development.* (Chapter 13)

On the institutional level the positioning in relation to staff competencies, recruitment and external funding sustain the disciplinary divide and results in continued controversies over the status of these in relation to the cross-disciplinary and heterogeneous project assignments that should prepare students for 'wicked' problem solving (Downey, 2005). Last but not least the findings in several articles show us that engineering jobs, even in cases where new practices seem obvious, are confined within existing business models and expectations that demonstrate their path dependency and challenge new types of engineers to become change agents within their business field. This does not imply that business and government employers are not asking for new competences, but that the transformation also in business is locked-in to many dominant, existing institutional routines and organizational forms and expectations.

Formal institutions (universities, workplaces) often declare one thing – an open and inclusive perspective – and require another in their practices and daily norms and routines. Although change seems difficult, it does occur, albeit in a piecemeal fashion: user experience in car manufacturing design, project based learning reforms at universities, introduction of socio-technical competences, focus on environmental responsibilities, user involvement in design, qualitative methods of communication, etc. Change both in the disciplinary universe of research based engineering education institutions as well as in companies employing engineers is challenging. It takes a lot of effort to achieve these changes for an engineering profession that gains its position through these institutions at the same time as transformative agendas demand radical changes that fundamentally challenge their values and routines, as in the cases of sustainability, user centric design, and social engagement.

IDENTITY FORMATION IN ENGINEERING

A number of contributions in this book tellingly reveal the contradictions between sayings and doings, especially those analyzing in one way or another students' identity formation during their studies. While institutions may emphasize the need for students to adopt a professional attitude, very often the intellectual pressure from studying and elitist values result in the establishment of separate and competing sub-cultures among students, revealing what in educational studies has been called the 'hidden curriculum' that leads students to respond to actual demands rather to intended outcomes and values.

Tonso's contribution fleshes out in detail how different and even conflicting identities are constructed in university campuses both via curricular and extracurricular activities. At first the author reflects on the creation of stylized characteristics attached to students via their study performance and social behavior demonstrating an underlying gendering of social behavior as aligned with female values while theoretical and tactical study practices are seen as the norm. She pays particular attention to how these identities are at play in a capstone project where a senior engineer takes a group of students to visit his company in order to perform project related activities. In this setting it is revealed that those students that excel in formal academic activities have trouble coping with the new challenges of a working environment. This reveals a gap between what makes a good engineering student, as measured by performance in disciplines and exams, and what makes a good professional engineer.

> *Engineering schools engineer identities proved the loci for learning to belong and for learning to practice what counted as engineering on campus. But, students learned to belong to an engineering education community of practice, not an engineering community of practice (as envisioned by the design-reform rhetoric). … not all capable student engineers emerged as belonging, and the lack of a cultural language (engineer terms) for recognizing some students as engineers made some students (e.g., women who practiced design engineering, gays and lesbians) invisible as engineers (which signaled not belonging). … Thus, student engineers learned to embody past and current ways of campus life … taking up an intended scientific and technical curriculum (and for design-engineering practitioners a sociotechnical curriculum), as well as learning a complex unintended curriculum that encompassed cultural knowledge specific to this campus and to life in the US.* (Chapter 5)

The use of gendered categories of students' behavior, of recruitment, and of elements of professional practice is the core focus in the Lagesen's study of software engineering. The study demonstrates a rather dominant tendency within the field to view software engineering as a male discipline and practice, not least based on a student culture of nerds. It also shows a more general tendency in a number of studies and in popular media to gender the disciplinary practices within the field as masculine. Countering the efforts of recruiting women to study software engineering in e.g. Norway, the popular perception has contributed to maintaining an image of the field that persists in stark contrast to consultant companies' interest in recruiting women to oppose that image. While the popular image of female competences related to communication and empathy see these as crucial for user-oriented software development companies and professionals, the study points to the need for employing software engineers that combine coding with customer contact. The study compares the situations in Norway, California and Malaysia and shows that gender issues are treated very differently across these contexts. It concludes that software engineering in Malaysia is considered a liberating field for women as it is a new profession not subsumed into existing societal gendered norms.

> *I found gender in software engineering as part of very different … gender-and-software engineering assemblages … constituted by multiple and diverse interferences, thus 'gender' was enacted in very different ways, took different shapes, and constituted the heterogeneity of these assemblages. Interestingly, most of the interferences came from various sources outside the profession and took different forms: discourses, policies, research, norms, ethnicities, professionalization, numbers, expectations, and spatial concerns. Thus, there is no binary feminist policy to draw from this study. Rather, the study invites a cyborg feminist perspective … The findings in this chapter suggest that the hacker/geek culture of computing in western contexts may have been exaggerated in scholarship as a way to make sense of the low number of women in software engineering …* (Chapter 12)

A similar finding can be seen in Kamstrup's study of the implementation of the CDIO concept. In that case, even though the official intention was to bring into the education authentic problems and work practices, students' practices oriented themselves toward the 'actual' learning goals that were expressed through the actual demands of performing well on exams.

Other contributions are less explicit in their analysis of identity formation, but reveal aspects of it. For example, Juhl analyses how engineers value most the possibility of having one model that delivers all the answers on how a production company should function. This challenge and its connection to science is so well appreciated that creating abstract models is heralded as true engineering not because the models provide improved knowledge for production, but because they provide management with statements supporting visions of rationalization. The analysis also reveals the opening up for new competitions as illustrated in Juhl's conclusion:

> *physics and engineering's professional domains have entered into more direct competition … in which multiple producers and users of knowledge struggle to define the form and value of the knowledge being exchanged. … From one side we see engineering seeking professional credibility by transforming its modus operandi towards that of science, while physics from the other side pursues professional utility through extra-academic collaboration.* (Chapter 13)

These identities are not necessarily gender related as shown in the former cases, but relate to rather common ideas of what the objects of engineering are. Engineering seems divided between two different identities: on one side the engineer as a practice based problem solver with deep insight into the working of technology, and on the other side a person able to abstract and construct models and representations that operate as supporters of ideas of machination and optimization of processes as a rational endeavor.

Buch analyzes how a consultant company deliberately engages engineers with a background that is considered holistic to be able to work with a new, more proactive approach to climate challenges and through monitoring support change actions.

New engineering knowledge, skills, and competencies were thus needed to change the material-economic arrangements of the consultant company. The engineers should have a holistic mindset and be able to frame engineering problems more broadly and in innovative ways. When the general political landscape changed followed by changing customer needs and business perspectives the vision lost support changing also the role of engineers and their competences.

> *New learning practices can eventually contribute to changing substantive engineering work practices, but will not necessarily do so. As evidenced in my narrative, practices possess inertia and are influenced by more elements than individuals' dispositions, attitudes, knowledge, skills, and projects. The practice architecture of (substantive) practices is also determined by extra-individual elements, such as the practice landscape, i.e., the material-economic arrangements of the site, and the practice traditions/general understandings of the site. … Is it sufficient for educators and reformers to provide new knowledge, skills, and learning practices to students that might eventually, ceteris paribus, result in changing substantive engineering work practices at some point? Or … should we instead acknowledge the fact that practice ecologies can be hostile to new types of practices and that things do not hold constant most of the time? Instead of witnessing new learning practices being suffocated in hostile practice ecologies, might it be the ambition of educators and reformers to educate future engineers to survive in hostile practice ecologies and provide them with skills and tools for trying to reflectively and effectively change substantive work practices in holistic ways? And what about the companies that employ future engineers? Should they just expect future engineers to fit into existing practice ecologies? Or should they strive to adjust practice ecologies to become more welcoming to new ways of practicing engineering more holistically?* (Chapter 8)

Similarly, Petersen and Buch demonstrate how new approaches to engineering design addressing user experiences need to engage with how new approaches are to become embedded in existing organizational structures and need to engage with and relate to existing dominant practices. The designers in charge of users are peripheral to the company's organization, meaning that their expertise is still subservient to the 'real' engineering production of new car designs. This leads to the formation of alternative identities emphasizing the specifics of working with and translating user perspectives into an engineering design world of standards and optimization as well as efforts to identify fields of cooperation and to build interconnections between the different practices of design.

> *… engineering (or the products engineers develop) can be changed neither from the top nor the bottom. This case shows us that merely bringing in new engineers with new competencies or forming a new department with an alternative focus will not change much … Engineering practices do not exist*

> *in isolation within an organization, and a transformation therefore requires a change in the very ecologies of practices that exist across an organization. … Alternative perspectives also mean alternative ways of approaching a task and evaluating the successful of the result. To a great extent, organizational structures, running across departments and management layers, frame what is possible in the everyday life of a workplace.* (Chapter 9)

Something similar but related to engineering educational institutions is shown in the contribution from Valderrama, Brodersen and Jørgensen in their study of the uptake of environmental, energy and climate challenges in engineering education. The many ways in which the environment as a social concern could be included in programs on Environmental Engineering are gradually narrowed down to those aspects that could be translated to fit the core of engineering identity as already performed within the existing disciplines and educational framings. The result was a continuation of professional instrumentality that operationalizes the phenomena at stake into objects that are calculable and contribute to problem solving by means of technical processes and products.

In terms of identity, we can conclude that engineers are still predominantly portrayed as men who solve problems by applying science, constructing mathematical models and working in large organizations. This archetypical description of engineering identities is discussed in this book through contributions that show: how these are produced, how other alternatives are suppressed and how different aspects that fall out of its scope (users, the environment) are difficult to work with. Social norms and discourses reproduce such depictions even when they intend the opposite, which becomes visible in those cracks where norms are transgressed. Therefore, new norms of student attitudes, supported by de facto changed learning practices, are needed to avoid students being exposed to stressful contradictions at universities. An especially crucial problem is the instrumentality of exams not confirming program's learning goals.

WHAT IS ACHIEVED BY STUDYING ENGINEERING PRACTICES?

The main advantage of studying engineering professional work and educational activities with a practice theory approach is the integrative picture that is produced. A practice theory approach allows tracing in action the relations between institutions, objects, knowledges, identities and organizations. Therefore, this book provides insight into many hidden conflicting and controversial aspects, which are invisible when focusing in only one or two aspects of engineering professional work and/or education and ignoring the different scales of practices involved. They result from the role of technology as an ordering instrument and social alignments as well as exclusions. They are a result of a mindset and identity that seek rational procedures and standards even in cases where these favor an extension of machinating (reductionist) models to fields outside technical control such as e.g. human visions, organizations and values reductionist approaches rather than accepting the complexities involved. They result from the production of mathematical models delivering visions of optimization that are products of the models themselves. They tend to downplay the wicked character of problems that may appear mundane at first glance. These aspects become visible especially in the span between official, declared objective, policies and norms on one side and the actual routine practices on the other.

The authors in this book have deployed a variety of approaches within studies of practices and ethnographic methods like observation, interviewing and intervention to complement the quantitative, functional, instrumental and often normative and philosophy based studies of engineering and technology. They all share the integrative approach with special attention to materiality, skills and experience within both routine activities and situations of reflection where steps are taken to induce change.

Akera and Tang take inspiration from an approach often used in external assessments using interviewing and documents to unravel the priorities, visions and concerns of institutions in their response to changing policy regimes and governance frameworks like e.g. planning to extend an intellectually skilled workforce and innovations versus neo-liberal reform measures redistributing networked responsibilities to marked arrangements.

The other approaches inspired by different strands of practice theory range from Petersen and Buch, and Buch employing a combination of practice theory as proposed by Schatsky used to identify the daily routinized and performed practices and to unravel how these reflect understandings and normativities. This approach is complemented by the proposal of Star to identify infrastructural layers that operate across different practices and are relevant to explain some of the tensions within practices and how practices change. Based on interviews and observations Brodersen and Lindegaard have studied user conceptions in design practices and product policies by using the approach of Shove, stating that practices are shaped and reshaped by different meanings, competences and materiality. Valderama, Brodersen and Jørgensen attempt to identify the multifaceted societal challenges to engineering through a reading of the codes of meaning and the institutional frames that, according the Downey and Lucena, are instrumental in the translations of the challenges into objects of engineering that are familiar and can function as operational responses in problem solving.

Tonso in her empirical work was a participant observer of the organization of client related design projects and has observed and interviewed students about how they made sense of studying and becoming engineers through their building of identities. Kamstrup also combines observations with interviews and document analysis to identify how students and teachers enact reform initiatives, and how their daily-life practices reflect official policies of their everyday educational practices. In her study, she is inspired by Mol's concept of enactment and performs the observation taking Hastrup's advice of following the observed. Canney as well as Lagesen based their studies primarily on in-depth interviews and reflexive interpretations of what is spoken about and what left out or only indirectly addressed in the context of the interviews, but they also show how identity formation among students and in the discourse on gender produces specific images of engineering. In his work, Canney identifies pathways following a processual approach, while Lagesen engages with the concept of interference as introduced by Harraway and Moser to cope with the complexity of gender.

The analyses in the book provide an alternative to the idealized and simplified (distorted) view of engineering, which is common in the majority of literature about engineering. We claim that these dominant views tend to distort what is the bulk of engineering practices through exactly the idealization of core components (elements) of engineering work, regarding them as abstract organized knowable objects like mathematical models, science based methods and engineering objects (bridges, machines, devices, software). They black-box the heuristics and the assumptions needed to make these knowable objects operational and able to provide instrumental answers.

But isn't this exactly what engineering is about? The contrast to taking these idealization for granted, depicting engineers as persons using rational instruments and struggling to materialize these ideals and exhibiting an uncontroversial commitment to them, is to view engineering as a continued battle between the exploration of boundaries and the attempt to operationalize.

Practice studies, like the ones in this book, are a conscious effort to avoid these a priori idealizations and instead observe and analyze the actual sayings and doings of engineers. This provides the opportunity to observe the effort they put into making sense of the wickedness of the world using a heterogeneous repertoire of tools and strategies. In this sense, the orderly abstractions of engineering are not pre-existing engineering endeavors, but are a product of the efforts of engineers through their practices.

Comparing the contributions in this book with the contributions from what we in the introduction phrased as the 'practice turn in engineering studies', we can identify continuations as well as improvements. In the introductory chapter, we presented some of the earliest studies, while they will only be referred to briefly here (for references see Chapter 1). In the early contribution by Ferguson and the later by Henderson, the focus was on the role of visualization and drawings in engineering practice as a clear extension and difference to a codified science based practice. Working with sketches, technical drawings are not mere devices of illustration and representation but are devices of communication, demarcation and innovation that include the not-yet-named and codified. This was followed up in the work of Bucciarelli on design dialogues and sketches as means of making ideas come alive, named and reproducible. Compared to these fundamental studies, the practice studies in this book emphasize the complexities at different levels and in different settings, expanding the practices into the organizational context of engineering. In Vincenti's study, so eloquently named 'what engineers do', his focus was on the division of labor in engineering and the steps from concept development to production, showing all the heuristics, the testing, the assumptions and the lack of science based support that also goes into engineering. In the recent studies as well as the volume of William et al., engineering practice is viewed within its broader embedding in organizational, social and value based perspectives emphasizing how the identities of engineers and the conception of problems and challenges to be solved affect and influence practices.

The continuation of the studies of this book in relation to the earlier studies of practice in engineering lies in the focus on specific elements of practice like the role of the exchange of knowledge through different means of representations of knowledge in e.g. visualizations as well as the handling of the heterogeneous elements that engineers address in their problem solving. It demonstrates the continued challenge of articulation, interpretation, representation and delimitation in the detailed activities involved in problem solving whether it is part of an educational setting or a work setting. The improvements provided to the field and the practice studies approach lies in the richness of the case studies that add to the picture the institutional and disciplinary framings at play. Following this, they demonstrate how the controversies of engineering professional practices – both what they are and what they should become – are unfolded and a part of a distributed set of tensions and conflicts about the delimitations and perspectives to be involved in engineering professionalism.

CONCLUDING REFLECTIONS

The following, concluding section of this book attempt to broaden the scope of our discussion and reflect on the findings from the chapters and the condensed and crosscutting thematic discussion of these. We have organized these discussions in two themes: *the first* focusing on the interrelations between engineering education, work and the profession, and *the second* on how the challenges to engineering and technology open up new visions of an increasingly multi-faceted and divided profession.

All the contributions that focus on education have reflected – if not explicitly then indirectly – on the role of the 'hidden curriculum': instrumentality, calculability, tangible outcomes and core technical features that appear still to be maintained as dominant values of engineering. This perspective defines a rather general set of norms that continue to be an important contributor to the identification of the engineering profession and its operational influence and dominant position on technological development.

Engineering education and work practices exhibit conflicting directions as presented in the contributions. Some of the conflicts arise from the dislocation of ends and means (Juhl, Harders, Valderrama et al.). Others come from a dislocation of the norms proposed in education or developed among students and the ones provided in professional settings (Canney, Lagesen). Others can be viewed as technocratic and elitist ideas promoted through general ideas of technology and engineering not reflecting mundane practices (Tonso, Lagesen).

Existing codes of meanings among departmental staff and institutional frames and priorities e.g. supporting specific technical research and innovation strategies have shown to resist new scientific topics like ecology and climate studies, science and technology studies, and sustainability transitions as new subjects of research and teaching (Valderrama et al.). If such new topics demonstrate a capability to translatable into instrumental, calculable and technically tangible outcomes and methods they tend to be included. If this is not the case the topics in many cases only survive as add-on disciplines but not as core subjects that are invited to organize new departments.

The adaptation of a new institutional perspective of engineering as a socio-technical endeavor that includes the instrumental rationalities of machinery and techniques in a hybrid mode of reflection and application of technology seems to be crucial to changing the foundations of engineering. The historic transformation of engineering from being an instrumental part of a infrastructure based modernization of society to becoming a profession that supports different capitalist economic modes to prosper has profoundly changed engineering institutions and educational program, which are today more diverse than ever. Contemporary reform has to emphasize sustainable transitions that re-introduce nature and society as equally important to technology.

On the Societal Challenges to the Engineering Profession

The studies have demonstrated that institutional and disciplinary frames operate as translation devices via values, codes of meaning, etc. and prioritize, magnify and marginalize aspects of the societal challenges – be they environmental, social, user oriented or more integrative as in the case of sustainability – in relation to what is supported as the dominant features of engineering professionalism. This despite the observation in many of the studies that the activities that are part of the practices in the work and educational settings are characterized by their indeterminate and complex elements that illustrate the limitation to the mere instrumental and commercial visions and all the effort that goes with making these become socially operational. This can be interpreted as ‘implementation’ activities that are specific to places and situations and do not influence the core of engineering knowledge even though it takes time and defines objects of engineering work. More likely it illustrates the aspect of engineering professionalism that is related to the building of social control as an intrinsic and important part of the technical solutions produced by engineers though not being a core part of most engineering training.

This raises the question whether engineering has developed into – or even always has been – a profession in which institutional and commercial interests frame and define the problems to be solved, reducing the engineering profession to a group of practitioners that solve problems effectively and efficient within the provided specifications and without seriously challenging the economic and social values behind making engineering an instrumental means to achieve stated ends?

Worried by the fact that the engineering profession has evolved reactively to developments in technology and society, engineering managers in the US National

Academy of Engineering developed a forecasting exercise. They asked questions like: “What will or should engineering be like in 2020? Will it be a reflection of the engineering of today and its past growth patterns or will it be fundamentally different? Most importantly, can the engineering profession play a role in shaping its own future?” Their conclusion was that “Whatever the answers to these questions, without doubt, difficult problems and opportunities lie ahead that will call for engineering solutions and the talents of a creative engineering mindset” (NAE, 2004). The report ‘The Engineer of 2020’ goes on to analyze the consequences for engineering professionalism as condensed in the following:

> *The economy in which we will work will be strongly influenced by the global marketplace for engineering services, a growing need for interdisciplinary and system based approaches, demands for customerization, and an increasingly diverse talent pool. The steady integration of technology in our infrastructure and lives calls for more involvement by engineers in the setting of public policy and in participation in the civic arena.* (NAE, 2004:4)

> *Engineering is a profoundly creative process. A most elegant description is that engineering is about design under constraint. The engineer designs devices, components, subsystems, and systems and, to create a successful design, in the sense that it leads directly or indirectly to an improvement in our quality of life, must work within the constraints provided by technical, economic, business, political, social, and ethical issues. Technology is the outcome of engineering; it is rare that science translates directly to technology, just as it is not true that engineering is just applied science. Historically, technological advances, such as the airplane, steam engine, and internal combustion engine, have occurred before the underlying science was developed to explain how they work. Yet, of course, when such explanations were forthcoming, they helped drive refinements that made the technology more valuable still.* (NAE, 2004)

Though emphasizing the creativity and design element of engineering and recognizing the intricate relationship between technology and science, the report alludes to an image of engineering as providing technical solutions based on the talents of engineering professionals.

This report has since been followed up by the NAE report on ‘Grand Challenges for Engineering’ (NAE, 2008), which is introduced by the statement:

> *Throughout human history, engineering has driven the advance of civilization. … In the modern era, the Industrial Revolution brought engineering’s influence to every niche of life … In the century just ended, engineering recorded its grandest accomplishments. The widespread development and distribution of electricity and clean water, automobiles and airplanes, radio and television, … highlights from a century in which engineering revolutionized and improved virtually every aspect of human life.* (NAE, 2008:1–2)

While these achievements undoubtedly are part of civilization and development in the modern age, two elements of the grandeur presented are quite problematic. The first is making engineering an effort that precedes the profession and its change from being grounded in practical skills and experiences to being increasingly aligned with scientific endeavors. The second is the heroic position of engineering at the core of these changes and achievements without in any way reflecting the social, institutional and economic changes so embedded in the process of paving the way and installing this development that in the statement is narrowed down to technical devices and infrastructures.

Presenting engineering in this heroic fashion within this approach implies a simplified linear deduction from societal challenges to technical solutions with engineering and science as the core providers of solutions. This is clearly illustrated by the statements:

> *None of these challenges will be met, however, without finding ways to overcome the barriers that block their accomplishment. Most obviously, engineering solutions must always be designed with economic considerations in mind – for instance, despite environmental regulations, cheaper polluting technologies often remain preferred over more expensive, clean technologies. … Engineers must also face formidable political obstacles. In many parts of the world, entrenched groups benefiting from old systems wield political power that blocks new enterprises. … The ultimate users of engineering's products are people with individual and personal concerns, and in many cases, resistance to new ways of doing things will have to be overcome.* (NAE, 2008:5)

Clearly summarized in the margin note of the report:

> *Governmental and institutional, political and economic, and personal and social barriers will repeatedly arise to impede the pursuit of solutions to problems.* (ibid.)

Starting out with a question about the engineering profession being too reactive to societal challenges, this engineering science focused approach ends up neglecting historic experiences with societal controversies and complexities being a crucial element in the overall socio-technical change that has emerged, and focuses solely on engineering as the autonomous response to future needs. While societal challenges are reflected in this approach, it re-iterates the technocratic vision that places engineering at the core without asking questions of how the mere focus on technical solutions will provide this new role to engineering.

It can be argued the 'Engineering 2020' and the 'Grand Challenges' approaches to engineering professionalism are particular to the United States. However, the United Nations has also expressed concerns about the role of engineering in solving the most pressing development challenges of the world.

> *Such large-scale challenges include access to affordable health care; tackling the coupled issues of energy, transportation and climate change; providing more equitable access to information for our populations; clean drinking water; natural and man-made disaster mitigation, environmental protection and natural resource management, among numerous others.* (Wall, 2010:5)

Similar ideas to these presented by the US NAE are presented in countries of the EU e.g. by the British Royal Academy of Engineering in the report on 'Global Grand Challenges' and by the Danish Engineers Association (IDA) in their present 'Engineering the Future' visions. Following up on a number of the specific, future technical solutions to societal challenges, they present visions and perspectives following the same line of arguments concerning the role of engineering professionalism.

Such images of engineering present a self-contained and confined professional group that provides heroic technical solutions to problems despite the obstacles of politics, commerce and people. These images are important elements in attempts to promote the profession as a human endeavor on one side and on the other to provide the profession with self-esteem and identity. The studies in this book demonstrated that engineering identity formation is not limited to the impact of e.g. educational institutions and their 'hidden curricula' on students. This process is performed in a broader societal context, where images of technology, science and engineering often present the same type of monolithic, heroic images of engineering's role in societal development and change. Such images not only operate for good in identity formation, but also they propagate a potentially limited image of engineering as a technocratic, predetermined and exclusive professional practice.

While these visionaries for the future take their starting point in some of the same challenges that were the starting point of the studies that we have presented in this book, and asking similar questions about the role of engineering knowledge, its scientific and experience basis and the perspectives for engineering professionalism, the results point in rather different directions. The views expressed in the engineering institutions' visions focus on technical solutions based on the sciences as providers of classifications, models and solutions tend to reduce and focus in depth on partial techniques, which handle the societal context as a potential barrier to change. They also tend to classify experiences into well-defined categories of nature, technology and social issues, preferring solutions limited to more or less autonomous machination based approaches. In contrast – though not denying the importance of specific techniques and sciences as elements of the heterogeneous work of engineers – the lessons from the studies presented throughout this book point to science and engineering work as tools and heuristics for exploration and problem identification in a much less confined sense. Consequently engineering solutions and their impact on establishing a division between the techniques and the social are not expected to pre-exist. Pre-defined classifications taken as the starting point may limit the ability to explore the problems to be solved and thereby frame and direct the visions and solution spaces of engineering. In contrast the piecemeal engineering approaches that include other fields of knowledge from other sciences and practices that are open to public involvement and socio-technical change opens for a wider set of suggestions and possible outcomes.

While the practices of engineering professionals in many ways are increasingly varied, and questions can be raised concerning the coherence of an engineering profession with a common identity, engineering still operates as a professional field of its own with practices in a variety of specializations. Some of these – as shown in the studies – are increasingly being integrated and require further integration of knowledge and practices from other fields engaging with political, commercial and socio-material entities. The idea of an engineer being a person that applies the laws of nature in a way leading to socially useful technologies may have bearing in very specialized fields of engineering science and technical problem solving, where design concepts and solution spaces are predetermined already. But it does not satisfy the broader need for new competences within engineering that make professionals able to handle the processes of cooperation and problem identification in relation to tackling the open-ended aspects of engineering design. At least not if these shall provide solutions that include the technology's role as socio-technical ordering processes and is dependent of the involvement of a variety of actors in making technologies operational.

On the Interrelations between Engineering Education, Work and Profession

From the outset the contributions in this book apply a multi-sited approach to engineering by including both education and work as equal sites of practice, not favoring one site over the other. The point is that both engineering education and engineering work practices contribute to the development of the engineering profession. The book also includes studies at different scales from the level of institutional and company organization to the details of teaching and work practices. This stays in contrast to the dominant belief in government, employers' organizations and even several research approaches to educational planning that view engineering tasks and competences constituted within industries, consultancies, and public institutions that employ engineers. The assumption is that they set the standards, develop the future practices, and consequently can define the engineering competences needed to be achieved by educational programs. The model operates as a division of demand and supply, where work situations define the demand and educational ends are defined on the supply side. Though the role of education as provider of the workforce of the future at a superficial level seems to support this model, studies of settings where new technologies, societal challenges and work practices are developed do not support this picture. These are also the lessons we can draw from the studies presented in this book.

As an element in the discussion putting emphasis on a 'gap' between education and work contemporary politicians and engineering educators are preoccupied by the lack of recruitment into engineering and science educational programs. The concern is, how to address what is identified as a shortage of engineering professionals and not least engineering students in richer countries, especially while the number of students in engineering programs in countries with emerging industries is increasing. The contributions in this book do not address this issue directly. However, the lack of recruitment to engineering education is closely related to the core issues of engineering addressed in this book: lack of a strong connection to societal issues, the reification of the male identity of engineers and the insistence of engineering knowledge being mainly applied mathematics and physics with an instrumental view of technology as technical procedures and solutions. The former section illustrated the engagement from institutions speaking on behalf of engineering. But also how they fail to open engineering to problem identification in relation to the societal challenges and instead argue for solutions to come from technical knowledge and methods. The lack of recognition of diversity in gender perspectives and in societal engagements in the way engineering programs address problem solving might in fact also be the most important barrier to improving recruitment.

Changes in technology, in the societal and business conditions for the application of technology and in the knowledge, heuristics and methods employed in the engineering profession have multiple origins, and a simplistic labor market demand model does not appear very promising in this context. In contrast, it seems to be potentially counterproductive and conservationist for engineering professionalism in both of the dimensions discusses in the former section on challenges. The controversies regarding how and by which means engineering practices need to be changed by introducing new fields of knowledge and practices must not be restricted to the views and interests of confined groups of employers.

So where does change in the content of engineering practice, knowledge and professionalism come from? The lessons from these studies tell us that these changes result from an intricate interplay between a number of different settings and practices, all enacting existing practices as well as stretching these and performing new perspectives. These include: professional discussions, workplace changes, new tasks taken up in engineering consultancies, new companies emerging from entrepreneurial activities, grassroots engagements and changes in institutional politics among engineering schools, disciplinary developments, concepts of learning and how students engage with societal problems, as well as new interdisciplinary developments.

While the link between the educational setting and the employment of engineers in specific workplaces is dependent on the engineering graduates being able to tackle existing knowledge formations and practices, this does not in any way reflect or satisfy the need for renewal as discussed in the former section. The renewal of engineering practices come from a variety of sources including new design methods, new ways of including actors, customers, and citizens in change processes to reach out for sustainable solutions, as well as new scientific results and new developments in open ended knowledge and practice. The obstacles changing engineering practices are manifest and originate not one-sidedly from societal conservatism, but arise from existing business models, from students, teachers and administrators prioritising technical rationales and from reductionist perspectives in existing scientific disciplines.

In this context, engineering educational reform plays an important role as it contributes to creating variation and setting new standards as well as providing opportunities for the adoption of new methods and analytical approaches that enrich engineering professionalism. These include establishing a richer and more varied set of engineering programs and moving beyond the idea that the natural sciences define the standard of thought in the very instrumental version defining engineering core curriculum. This need for variety was also addressed as 'expansive disintegration' reflecting the large number of new programs, disciplines, and technical objects (Williams, 2003).

The studies presented in this book show how engineers who engage with technology from an instrumental perspective viewing engineering as the provision of technical solutions end up having difficulties in handling the societal challenges and opening up for a broader variety of knowledge involved in analyzing problems. One solution has even been to enhance the science-based curriculum in engineering. Others have focused on learning and training through engagement with engineering problem solving, while others have questioned the relevance of having engineering schools at all or defined new engineering programs that include a strong element of liberal arts.

Interdisciplinary competences are crucial at the individual level for the ability of engineers to consider alternative perspectives and visions and to be able to cooperate and include other perspectives than the instrumental coming out of technical sciences with their already established objects and conceptually defined solutions. But whether these competences also address the need for individual engineers to be competent in all aspects of their work is questionable. Contemporary and future work practices will increasingly be the outcome of collective work bringing different skills together, and combining and assembling them. It involves skills to be able to cooperate, which is more than the ability to work in teams, but include the ability to analyze and identify the problems at stake and not least the ability to stage processes that include problem identification, structuring tasks, and identification of relevant approaches for designing solutions.

The tendency to respond to new challenges by expanding curricula with further add-ons whenever new challenges are faced does not respond to the need to carry out a more profound reform of the core perspective and training in engineering education. Our experience from specific practices performed in work and education related tasks and project assignments suggest that emphasis in engineering curriculum should reflect the broadening of engineering challenges. This would include providing space for the process of problem analysis and formulation, for the understanding the socio-technical nature of engineering work and the importance of conceptual design.

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