TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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What Engineering Scientists Know and How They Know It

Towards Understanding the Philosophy of Engineering Science in Finland

Julkaisu 1344 • Publication 1344

Tampere 2015

Tampereen teknillinen yliopisto. Julkaisu 1344
Tampere University of Technology. Publication 1344

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Thesis for the degree of Doctor of Science in Technology to be presented with due permission for public examination and criticism in Rakennustalo Building, Auditorium RG202, at Tampere University of Technology, on the 20th of November 2015, at 12 noon.

Tampereen teknillinen yliopisto - Tampere University of Technology
Tampere 2015

ISBN 978-952-15-3619-9 (printed)
ISBN 978-952-15-3641-0 (PDF)
ISSN 1459-2045

Abstract

Knowledge, research and science are all concepts into which every member of the scientific community must have some kind of insight. Although nowadays there appears to be a general consensus that engineering science is a scientific enterprise in and of its own, this has not been the case for very long. As a scientific discipline, engineering science has been somewhat neglected from the standpoint of epistemology and philosophy.

This study aims at understanding the prevailing philosophy of engineering science in Finland. It strives to comprehend the essence and challenges of knowledge and knowledge-creation processes in the field. It is hoped that the resulting comprehension will improve the research community's possibilities 1) to reflect critically upon its procedures, 2) to discuss what should be studied and how, and 3) to determine on what bases the processes and results should be evaluated. It is also expected to assist in developing doctoral education and to result in better supervision by providing a framework and vocabulary for philosophical and methodological discussion.

The cognitive interest in this study is practical, and the orientation hermeneutic. The process follows the general lines of qualitative research and applies the method of qualitative content analysis. As an empirical inquiry, this study belongs to the realm of science and technology studies. The phenomenon was studied in the context of Finland in the guise of a single-case study, with Tampere University of Technology as the case.

The final results support the view that engineering science certainly is a scientific discipline in and of its own, characterised by its own technical matrix. Most engineering science research can be classified as design science. Scientific inquiry in engineering science often requires building conceptual—but also material—constructs, as well as developing new methods for different purposes (analyses, design, implementation, evaluation). Consequently, the contributions recognised in research are of many types (artefacts, methods, declarative knowledge, proposals), but they are not always the kind of knowledge adhering to technical norms. Arriving at new theories or linking knowledge to existing theories seems to be even rarer than arriving at technical norms.

Engineering science is a discipline of considerable diversity. The objectives, methods, empirical processes and results pertaining to one type of inquiry can be very different from those found in other types of investigation. This study uncovered five distinct research profiles, but there may well be more to discover.

At the moment, the philosophy of engineering science has not raised significant interest, as it appears not to have many direct consequences; yet, there are challenges that engineering scientists face that may well be rooted in the lack of common understanding about the epistemic, ontological and methodological issues of the topic.

Keywords: engineering science, philosophy of science, design science, epistemology, doctoral education

Acknowledgements

> *Kannattaa uskoo et onnistuu, vaik ei ois hajuukaa kui se tehää! [It's worth believing that you can do it, even if you don't have a clue about how to do it!] (Virkku Koukkunen)*

When I started this journey I had very little clues about how to go on with it. Luckily I have received a lot of help and support from different people along the way and I wish to thank all of them for that.

The most valuable guidance I have received from my two supervisors, Professor Hannu Kärkkäinen and Professor Samuli Pekkola. The "good cop" and the "bad cop" (shifting the roles) challenged me relentlessly and forced me to look at things from different angles. I am also indebted to the pre-examiners Dr. Jani Ursin and Professor Peter Kroes for their insightful comments and good questions concerning the manuscript, and to Mrs. Christine Silventoinen for her thorough proofreading.

From the very early days of my life my ambitions have been respected and my abilities believed in. For this I wish to thank my mother Anneli and father Pertti. As my mom is a living illustration of a lifelong learner, she has also set me an example, which I have tried to follow as well as I could. My late father witnessed my graduation as an engineer and was proud of me then. I just wish, that somehow he sees also this moment, as I am sure, he would be even more proud now.

Being more of a hobbyist than a professional researcher I have every now and then missed the opportunity to have peer discussions and support. Thank you, Hanna, Mikko and Pertti, for providing me with these on the home stretch of this project. My dear children, Reko, Verna and Petra, have set my priorities straight, managed to keep relatively quiet during my "home working" hours, and bring the meaning to my life. Thanks for that, kids.

Should this work bring about any glory, half of it belongs to the man of many roles. He has been my financial support, shoulder to cry on, test animal for an audience, admirer of my wisdom(?), and many other things. My beloved husband Petri has been on my side from the very beginning of this project (see the prologue for details) till the now looming end. Will I ever be able to thank him enough for that?

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Prologue

The seeds for this dissertation were sown about fourteen years ago when both my then boyfriend (now my husband) and I were working on our master's theses in engineering. One day, a friend of mine who was working on her thesis for educational science asked me what the framework of my thesis was. I cannot recall whether she meant the methodological or theoretical framework, but in either case I could not answer her as I had never heard the term *framework* before in relation to engineering research. So I mumbled something along the lines of my work being design rather than research work. This was actually true, but the answer did not sound very convincing even to my own ears.

Soon after that, Pete got feedback from his supervising professor. He said, that although Pete's thesis represented a nice piece of engineering work, it did not possess any particular scientific research merits. Pete was slightly puzzled, as was I, since neither of us could figure out what would have produced research merits in a piece of work which, like mine, was ultimately a work of design in nature.

These incidents launched my search for the theoretical and methodological frameworks and criteria for "scientificity" suitable for engineering science. For the first couple of years I was looking for the answers in literature. I studied the history and philosophy of science, technology and engineering. Then I started to write my licentiate thesis on engineering education and combed through more literature on research methodology, applying some in practice, too. Yet I could not find satisfactory answers to my original questions.

After a while, I became convinced that the answers were not out there for me to simply find and read, but were rather contained in a much more hidden form. With this realisation commenced the actual dissertation work. I began to think where and how I could find the bits and pieces of information which would allow me to build my own knowledge and understanding of the phenomena that had been bothering me for quite some time.

As typically occurs, I think that I have found more questions than answers along the way. Nevertheless, I now feel that not only could I give better answers to those questions triggered than I could thirteen years ago, I also suspect that I understand some of the reasons why I was at the time so ill equipped to answer them. Hopefully, this dissertation will succeed in sharing this understanding with you.

1. Introduction

> *Not so very long ago most philosophers of science maintained that the subject-matter of this volume [Philosophy of technology and engineering sciences] was uninteresting and most ontologists claimed it was non-existent. It was thought to be uninteresting because technology was taken to be an applied science in which the application itself presented no new philosophical challenges. It was believed to be non-existent, because technological artefacts and systems did not live up to the criteria for being part of the ultimate inventory of the world. A combination of these two views leads to the rather fatal conclusion that the philosophy of technology and engineering sciences is boring stuff about non-existing entities! (Meijers, 2009, 1.)*

Knowledge, research and science are concepts which are difficult to define and challenging even to characterize. However, every member of the scientific community must have some kind of insight into or understanding of them. These days, there seems to be a general consensus that engineering science is an scientific enterprise in and of its own, featuring a methodology and body of knowledge distinct from pure and applied natural sciences (Hendricks et al. 2000), but this has not been the case for very long (Meijers 2009). Also, explicit instructions concerning the manner in which research is conducted in the field of engineering are often adopted from the natural sciences (see e.g. Airila & Pekkanen 2002). Some claim that in certain areas of engineering science, the bias in favour of the natural sciences still guides and restricts views on what is considered to be a good or even valid research approach (Hukka et al. 2007).

In addition, the concept of engineering science is a slippery one. Just as in the broader term *science*, engineering science sometimes refers to a certain body of knowledge, sometimes to a certain type of activity, sometimes to a certain community of people, and sometimes to institutions where a specific kind of inquiry is practiced (for a more detailed description of the meaning of the term *science*, see section 2.2). In this study, the term *engineering science* is mainly understood and used in accordance with a broad meaning encompassing the activities of inquiry, both research and design, and the body of knowledge produced from those activities in certain institutions (namely universities), with the intention of expanding the universal understanding of certain phenomena.

Johnston, Lee and McGregor (1996) have argued that engineering as a professional discipline has been inappropriately constrained by the discourses of commerce and science. In their view, it is the discourse of engineering science which has caused the discipline of engineering to become captive to the ideas developed within logical positivism, thus removing the engineering profession from its actual context. This, in turn, has rendered engineering incapable of carrying out the self-evaluation needed for renewal and regeneration of the professional practice, as the matters related to the social or environmental context of engineering are not named and thus also often remain unnoticed. (Ibid.) This lack of metadiscourse that would allow engineers to observe and reflect upon their culture from sociological, historical, ethical, philosophical and pedagogical perspectives has also been addressed by Christensen and Ernø-Kjølhede (2008). In their view, it results in insufficient skills for self-reflection, for interdisciplinary cooperation and for adjustment to changing conditions. In essence, the lack of metadiscourse results in insufficient skills for the renewal and regeneration of the professional discipline and practice.

Johnston et al.’s view of engineering science is typical to the time period when the article was written and is based on a view of engineering science as an applied natural science. Their view seems to be founded more on the basis of the undergraduate engineering curricula offered at universities than on the actual nature of engineering science practice. However, it demonstrates that the discourse of engineering science has traditionally had a strongly positivistic tone. It also implies that if the nature of engineering science practice is in reality more contextual and diverse than the applied natural science view assumes, the incapability of the discipline in self-evaluation and renewal may be extended to engineering science, too.

The narrowness of the discourse and the lack of appropriate language was noted in a very concrete way by Ahern, O'Connor, McRuairc, McNamara and O'Donnell (2012), who studied the ways in which critical thinking is advanced in university graduate education. They discovered that the academics' definitions of critical thinking were much better formed in non-technical disciplines than for example in engineering. In engineering, the "academics had clear ideas about the importance of critical thinking, but found it difficult to verbalise what it actually meant, falling more into the 'I know it when I see it' division" (ibid, 127). Yet, it appeared that the actual perception of the nature and attributes of critical thinking was rather similar across the technical and non-technical disciplines (ibid).

The above-described phenomenon is not unique to engineering science. Orlikowski and Baroudi (1991) have reported a similar situation in the information systems discipline. They discovered that information systems research articles clearly exhibit a prevailing set of assumptions regarding the nature of valid knowledge and acceptable way of conducting research in the field. These assumptions were strongly aligned with the positivistic epistemology. It seemed, however, that the assumptions were not consciously examined by the researchers, but were rather merely taken for granted within the research community. Also, Orlikowski and Baroudi (1991) found this situation to be dissatisfactory and expressed a view that employing a plurality of research perspectives would be beneficial for the field. This would require the researchers to be aware of their research traditions and to be open to the possibilities of other traditions.

Nevertheless, knowledge-creation of a high standard has been executed in the field of engineering science for decades. Following Kuhn’s (1996) ideas, the discipline can be perceived to be in a pre-paradigmatic stage where several competing paradigms are simultaneously present. Like in the case of information systems research, these rival thinking models are passed on from one generation to the next, mainly through indoctrination, and are thus rarely questioned.

1.1. The role of mental models in science

According to Kuhn (1996, 163–164) a common paradigm increases the effectiveness and efficiency of scientific problem-solving, as it frees the members of the research community from re-examining its first principles; i.e., the underlying assumptions concerning their research. In a pre-paradigmatic stage, this efficiency is yet to be fully achieved. Acquiring a common paradigm and reaching the stage of normal science mean committing to the same rules and standards for scientific practice (ibid, 11). This is undoubtedly difficult as long as the rules and standards are not openly and constructively discussed. Discussion, however, necessitates a common language, which involves some level of consensus of the concepts concerning the fundamentals of the topic.

In addition to problem-solving, academic research can also be viewed as a cultural activity (see e.g. Becher 1994; Ylijoki 1998). From that angle, the demands of systematic knowledge creation are coupled with a demand for the university also being a learning organisation, whose culture changes and adapts to the needs of the surrounding society. Now the science is expected not only to solve problems efficiently but to solve the right or appropriate problems. This too calls for open and constructive discussion as the appropriateness of the problems evolves with time and changes in the society. In engineering science and technological development, this kind of shift can be seen for example in the growing demand for user friendliness alongside technical performance and economic efficiency.

In order to be efficient in knowledge production and simultaneously a genuine learning organisation, the university needs to be able to foster learning at both individual and organisational levels. Kim (1993) has proposed a model which links together these two levels of learning. In Kim’s model, the transfer mechanism between individual and organisational learning comprises the shared mental models. Developing shared mental models is in turn dependent on individuals improving their mental models and making them explicit.

According to Kim's model, there can be four different kinds of learning in any group. Individual single-loop learning occurs when an individual takes action based on his/her observation of the environment and conceptual models, but the action and the environmental responses following the action do not alter the individual's metal models. Individual double-loop learning occurs when the action also affects the mental models, which then affect the way in which an individual perceives situations in the future. Organisation single-loop learning refers to a learning situation where an individual’s action results in an organisational action, but the individual's mental models do not become incorporated into the shared mental models. Organisational double-loop learning occurs when individual mental models affect the shared mental models, which then result in an organisational action. It requires the challenging of the group's deep-rooted norms and assumptions. These may be inaccessible due to being unknown, or known but undiscussable. (Ibid.)

The organisations' or community's double-loop learning cycles may break down in many places. Kim uses the term *situational learning* for the case in which an individual deals with a problem without changes resulting in his/her mental models. Kim uses the term *fragmented learning* to refer to instances where individual double-loop learning occurs, but where the link between the individual and the shared mental models is broken. He also points out that this is a typical problem at universities, which employ leading experts for research purposes but cannot use this expertise to run the institutions' own affairs.

In the context of the philosophy of science, the shared mental models depicted by Kim are much the same as the paradigms or disciplinary matrices introduced by Kuhn or the academic tribal cultures discussed by Becher (1994) and Ylijoki (1998). Thus, viewing the situation from any angle seems to indicate that explicating, examining and critically reflecting upon the mental models of scientific inquiry both at individual and organisational levels are key to promoting efficient action in academic knowledge building and management.

1.2. Teaching research in doctoral education

The basic purpose of doctoral education is to teach individuals how to conduct independent scientific research. The research assumptions adopted and methods preferred are heavily influenced by the doctoral program attended (Orlikowski & Baroudi 1991, 24). Learning to “do science” is not simple. In engineering, the adoption of a paradigm and the understanding of the rules of the scientific game may be even more challenging for a young scientist due to the implicit nature of and lack of discussion about the philosophical grounds of engineering science. Ahern at al. (2012) noted that greater awareness of academics from non-technical disciplines led to better and clearer learning objectives and assessment tasks for developing students' critical thinking skills than in engineering. In addition, paradigm acquisition through indoctrination is particularly likely to wear out and drive away individuals who would like to question or criticize some aspects of the field. Students become uncomfortable with the discursive limitations of their education without acknowledging why and become marginalised from the culture (Johnston et al. 1996).

Currently, there is an ongoing debate regarding the need for and nature of professional doctorates alongside traditional PhDs (see Banerjee & Morley 2013 or Taylor 2008). Although this debate has not been as active in Finnish educational settings or in engineering education, the central questions are nevertheless important and topical also in this context. These include questions concerning the relationship between theory and practice, the nature of knowledge produced by research, the methods suitable for field-based research, and the appropriate measures for assessing the quality of different types of research. On the whole, the essence of the debate is centred on the ability of contemporary academic research and postgraduate education to benefit practical processes in society.

This challenge has also been noted by Korhonen-Yrjänheikki (2011), who conducted futures research on the development of Finnish higher education in engineering. Her argument Delphi panel, consisting of 21 representatives of the primary stakeholders of Finnish engineering education, proposes that postgraduate education needs more interdisciplinarity and that "a profile of [a] more generalist type of PhDs [is] needed, [one] that ha[s] in-depth knowledge about how to conduct scientific research and [is] able to apply [student] knowledge and skills in several fields" (ibid, 196). Both interdisciplinarity and the conducting of scientific research are topics pertaining to the philosophy of science, which in contemporary engineering science is rarely discussed.

If researchers are indoctrinated into a certain research subculture rather than being explicitly introduced to the philosophical aspects that render the research scientific in that field, then in-depth knowledge is restricted to one type of scientific research and one kind of research process only. This most certainly does not promote interdisciplinarity or applicability of one's knowledge in several fields. On the contrary, accepting the assumptions of the dominant research perspective unquestioningly imposes inadvertent restrictions on the research (Orlikowski & Baroudi 1991, 7).

In addition to its negative aspect of transmitting a rather narrow view of scientific research, indoctrination is not the most efficient way of learning. Critical thinking is often mentioned as one of the key skills for scientific research. Being critical, however, is difficult if the target of criticism is not explicit, as in the case of indoctrination. Thus, students become accustomed to being critical with such details as measuring accuracy, but are not necessarily able to evaluate the big picture of the research process. They learn to do things right, but do not necessarily learn to do the right things—a feature central to the validity and credibility of scientific research.

The symptoms of the situation coalesce in the perceived quality of the supervision. In a national study about student experiences during their doctoral studies, experiences concerning the content of supervision of students enrolled in engineering programs were significantly worse than the experiences of students enrolled in all other disciplines. In particular, supervisors’ level of interest, methodological and theoretical supervision, and constructive criticism were perceived to be weak. (Hiltunen & Pasanen 2006.) One plausible explanation for the poor supervision is the lack of discourse and common language concerning the philosophical issues.

1.3. Objective of the study

As the philosophy of technology and engineering science has long been regarded as uninteresting (Meijers 2009, 1), and as its epistemology has been neglected (Hendricks et al. 2000, 277), attempts to explicate the nature of engineering science have been scarce. Although an effort has been made to understand the nature of knowledge and knowledge-creation processes in engineering (see e.g. Vincenti 1990, Ropohl 1997 or McGormick 1997), less attention has been paid to engineering science (see Eekels 2000 & 2001). With little debate at the international level, there has been even less discussion at the national level. The route of engineering entering into universities has been different in various parts of the world (see e.g. Channell 2009 and Jørgensen 2007). Thus, even the ideas already presented in the literature may not be directly applicable to the national context in Finland.

This study aims at understanding the prevailing philosophy of engineering science in Finland. It endeavours to comprehend the essence and challenges of knowledge and knowledge creation processes as they currently actually are rather than how they should be. Hence, the philosophy is perceived from a descriptive and not prescriptive point of view. This comprehension is then hoped to have an effect on the explication and refinement of the shared mental model of the engineering science community. In hermeneutic terms, the objective of the study is to achieve an intersubjective understanding of the essence of engineering science from the perspective of the philosophy of science. This is sought by answering specific research questions. **The main research question of this dissertation is: What is engineering science like as a scientific discipline?** The three related subsidiary research questions are as follows:

I. What are the essential features of engineering science?
II. What kind of philosophy of science does engineering science entail?
III. What sort of challenges does engineering science pose for junior researchers?

The research questions as well as the philosophical commitments behind them are presented more thoroughly in section 5.1. Intersubjective understanding is directed towards the attainment of consensus among the actors in the scientific tradition and enables action-oriented self-reflection (Habermas 1971, 310). In this case, the consensus achieved is hoped to advance the three realms of universities: education, research and societal interaction.

Intersubjective understanding improves the research community's possibilities for critically reflecting upon its procedures, meaning that the community discusses what should be studied and how, and on what bases the processes and results should be evaluated. It also helps in introducing the rules of the game to novices through systematic training in doctoral education, and can result in better supervision by providing a framework and vocabulary for philosophical and methodological discussion. In addition to enhancing discussion within the discipline, an improved explication of the fundamentals of research can advance the discussion across disciplines and with society at large. Although the purpose of technology is to serve society, the language of engineering science may be such that this ultimate goal has remained largely implicit and is thus not conveyed to outside audiences.

1.4. Structure of the dissertation

The written thesis consists of ten chapters, whose content and relatedness are illustrated in Figure 1.

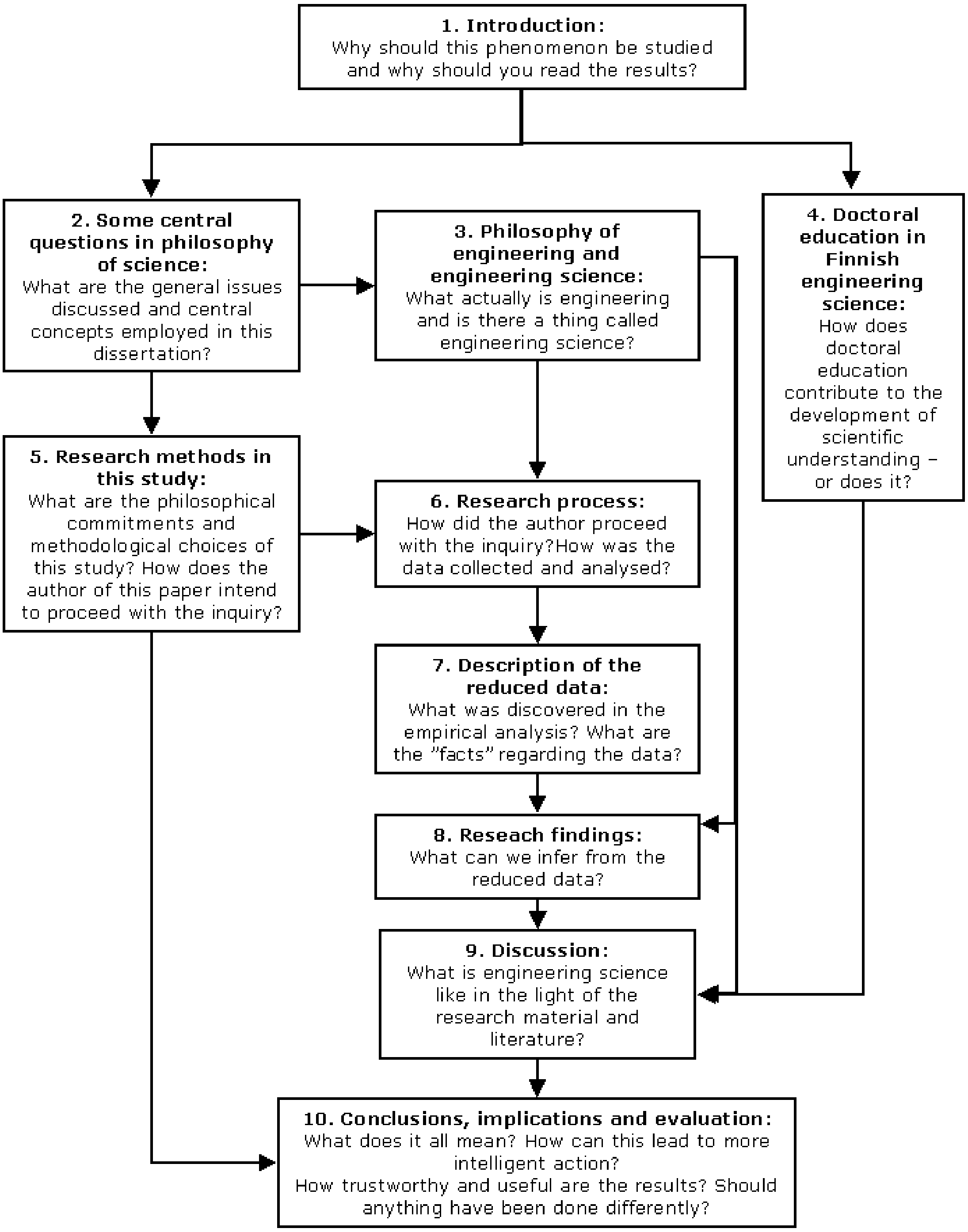

Figure 1. The structure of the thesis

Chapter One serves as an introduction to the topic. Chapters Two to Four set the theoretical framework of the study. Chapter Five sets the methodological framework of the study. Chapters Six to Eight present the empirical work and results. Chapter Nine evaluates the quality of the conducted research. Lastly, Chapter Ten presents the final conclusions.

The introduction explains the motivation behind the study. In addition, it states the objectives of the dissertation and describes its logic and structure. Chapter Two introduces the reader briefly to the basic concepts and topics of the philosophy of science in general. It discusses the purpose of science, the nature of scientific knowledge and scientific inquiry, and the norms applied in the scientific community. Finally, the relationship between science and design is viewed from different angles, and the concept of design science is introduced.

Chapter Three concentrates on the philosophical aspects of technology, engineering and engineering science. The relationship between them is defined, and the ideas of knowledge and knowledge creation in these various settings are discussed. Parallel to science in general, the norms and evaluation are also investigated with respect to engineering science research.

Chapter Four describes the context of doctoral education in Finland and, more specifically, in Finnish engineering science. The reader is informed about the degree structure and certain demographic elements of doctoral education in engineering. Also, some challenges regarding doctoral education noted in previous literature are pointed out.

Chapter Five outlines the methodology of this study. First, it sets the research questions and reveals the philosophical commitments and assumptions underlying the study. Then, it introduces the methodological choices made in the study. Finally, it briefly discusses the means for ensuring the scientific quality of the research.

Chapter Six describes the process of empirical inquiry, from collecting data to analysing and reporting the results. This chapter is separate from Chapter Seven, which also addresses empirical inquiry but focuses on reporting the reduced empirical data. This separation was made to enhance the readers' view of how the data reduction process was done and what was found as a result of that—a separation that sometimes proves to be challenging in qualitative research.

Chapter Eight discusses the actual phenomena behind the empirical notions. The reduced data is elaborated upon with quotations and theoretical findings from Chapters Three and Four. Central findings are summarised and discussed in Chapter Nine in the form of the answers to the research questions.

Finally, Chapter Ten contains the final conclusions about the meaning and usability of the results by arriving at several theoretical claims as well as practical recommendations. The inquiry process and products are evaluated by answering the questions set for the study in Chapter Five. Quality is discussed through the questions of truth-value, applicability, consistency, neutrality, publicity and novelty. Chapter Ten ends with recommendations for further research.

2. Some central questions in the philosophy of science

> *The term “theory of knowledge” or “epistemology”, was coined only in the 19th century; but the subject that it retrospectively denotes is the subject of modern philosophy in general, at least until the threshold of 19th century. The characteristic endeavour of both rationalistic and empiricist thought was directed likewise at the metaphysical demarcation of the realm of objects and the logical and psychological justification of the validity of natural science characterized by formalized language and experiment. Yet no matter how much modern physics, which combined so effectively the rigor of mathematical form with the amplitude of controlled experience, was the model for clear and distinct knowledge, modern science did not coincide with knowledge as such. In this period what characterized philosophy’s position with regard to science was precisely that science was accorded its legitimate place only by unequivocally philosophical knowledge. Theories of knowledge did not limit themselves to the explication of scientific method – they did not merge with the philosophy of science. (Habermas 1971, 3.)*

Although this study quite clearly pertains to the realm of the philosophy of science and draws heavily from the discussions and thoughts within that, the above-quoted viewpoint is important to keep in mind. Many of the philosophical problems concerning the engineering sciences emerge from the “misfit” with the format on contemporary (natural) science.

The purpose of the following brief dive into the world of the philosophy of science is to define the philosophical concepts and their relatedness to this study. It also shows the variance of these concepts throughout history and links to often hidden presuppositions which have prevailed during certain periods of time. These concepts are then used in Chapter Three to describe and analyse what has earlier been written about the philosophy of engineering science. The concept of design science is paid special attention, as the role of design is central in engineering practice (see e.g. Vincenti 1990), and it is discussed also with respect to engineering science (see e.g. Simon 1996).

2.1. Epistemology and the philosophy of science

Epistemology is the branch of philosophy concerned with questions relating to the nature and origin of knowledge. It also investigates the possibility and limits of knowing, the process of knowing and the concept of truth. (Haaparanta & Niiniluoto 1993, 18.)

As the quotation at the beginning of this chapter illustrates, this area of philosophical investigation was named after the birth of contemporary science, but as a philosophical question, it existed long before anything we would nowadays regard as scientific inquiry. According to Habermas (1971, 71), the replacing of general epistemology with the philosophy of science was part of a “pseudo-scientific propagation of the cognitive monopoly of science” promoted by the early positivists such as Comte. This created a situation in which knowledge became identical to scientific knowledge, and science could only be defined by the methodological rules according to which it proceeds (ibid). This strong connection between knowledge and scientific methodology still remains, even if many of the other ideas of the early positivists have been abandoned.

In the beginning of the 20th century, the philosophy of science was strongly connected to the ways of thinking of the successors of the early positivists, who were the logical positivists and logical empirists. Philosophical interest was still present in the scientific methodology, and the aim of philosophy was to reconstruct the scientific method by looking at its products. (Kiikeri & Ylikoski 2004, 53; Okasha 2002, 78) The philosophers were not interested in the history of science but instead in the formalisation of scientific inquiry, with logic being perceived to be the main tool of the philosophy of science (Godfrey-Smith 2003).

Moving towards the end of the 20th century, the use of historical evidence in solving the problems of scientific thinking began to gain popularity. At first, history was used as evidence to support certain reconstructions or to clarify some instances related to them. Since a naturalistic turn was taken in the philosophy of science at the end of the 20th century, the history of science has become a tool more for describing the processes and debates surrounding the epistemological issues than for merely supporting the prescribed processes. (Kiikeri & Ylikoski 2004, 54-55.) Further, Godfrey-Smith (2003) suggests that naturalists believe that an attempt to provide a general philosophical foundation for science is a project doomed to fail and is therefore unnecessary. This shift towards “how things are” instead of “how things ought to be” also brings the epistemological questions closer to the interests of sociology or the history of science.

2.2. The purpose of science

The word *science* is far from being unequivocal in terms of a definition. Kiikeri and Ylikoski (2003, 16) distinguish among the following six different meanings:

1. Science as the results achieved so far by scientific inquiry (things that are considered to be true at the moment)
2. Science as the results to be achieved by scientific inquiry (the final truth)
3. Science as the methodology used currently in scientific inquiry
4. Science as the methodology which should be used in scientific inquiry
5. Science as the community of people doing scientific inquiry (the so-called scientific community)
6. Science as the institutions where scientific inquiry is practiced (e.g. universities)

These six attributions are closely related to each other, and most of the time we recognise by the context the attribution that is used (ibid). In line with the previously described naturalistic turn in the philosophy of science, Klemke (1998) suggests that in philosophical debates, the characterisation of science has commonly been related to the method used for obtaining knowledge, and that this characterisation has been recently challenged by the view of science as a body of knowledge. Ziman (1968) also addresses the social aspects of science. He argues that a distinction among science as a body of knowledge, science as scientists' activities, and science as a social institution should not be made, as the division hinders us from characterising science as a whole.

The purpose of science naturally also differs according to the different meanings of the term. Haaparanta and Niiniluoto (1993) state that the purpose of science is to systematically and rationally create new knowledge. This view is called cognitivism. According to the cognitivistic view of science, the results of science are "sentences" presenting statements about the state of art of matters in the world. The cognitivists can further be divided into two camps: verists, for whom the primary criteria of knowledge produced by scientific inquiry is the truth; and informationists, who instead of the truth pursue the best possible information about the world (Niiniluoto 1980, 73). Ziman (1968) extends the informationist view to a social dimension by suggesting that the goal of science is "a consensus of rational opinion over the widest possible field."

The opposite view of cognitivism is behaviouralism, a view held by behaviouralists. According to behaviouralism, scientific problems are in fact decision-making problems, and the results of science are thus recommendations for action. (ibid, 9-10.) This kind of practice-oriented view of science is also held by the instrumentalists, who regard scientific theories as instruments for predicting observational phenomena rather than descriptions of nature of reality (Okasha 2002, 60). This view is represented by Frank (1954), for example. The cognitivist versus behaviouralist views on science are more related to science as results (meanings 1 and 2 of Kiikeri and Ylikoski's definitions above) than as the science as methodology (meanings 3 and 4) or as a social organisation (meanings 5 and 6).

When we focus on the methodology of scientific inquiry, the purpose of science can be approached through the lens of the objectives we place on scientific research. In the field of natural sciences, where the scientific method is often based on the making and testing of hypothesis, the aim of science is often classified as to describe, to explain, to predict and to control (see e.g. Järvinen 2004, 8). According to Klemke (1998), we must distinguish between science as knowledge, referred to as pure science, and the applications of science, referred to as applied sciences. Along with this distinction, the aims of pure science are often considered to be description, explanation and prediction; and the aims of applied science include control, planning and technological progress (ibid). In the humanities, the research is often thought to be carried out with the hermeneutical method, which aims at describing and interpreting (Haaparanta & Niiniluoto 1993, 64).

Simon (1996, 1) describes natural science as a body of knowledge about objects or phenomena in the world, characteristics and properties of those objects or phenomena, and the way they behave and interact with each other. He also points out that the world in which we live today is more man-made than natural, with almost every element in it showing evidence of human artifice. This tie between human purposes and natural laws has important implications for certain areas of knowledge (economics, psychology and design in particular), which Simon calls "the sciences of the artificial." Järvinen (2004, 8) also addresses the problem of studying the building of artefacts and suggests that a purpose of scientific inquiry can also be to engineer/construct, to understand (systems), to re-engineer and to evaluate. These are rather similar to Klemke's aims for applied sciences, with control and planning approaching ideas of engineering and understanding systems, and technological progress referring to activities akin to re-engineering and evaluating.

The different objectives of scientific inquiry are illustrated in Figure 2.

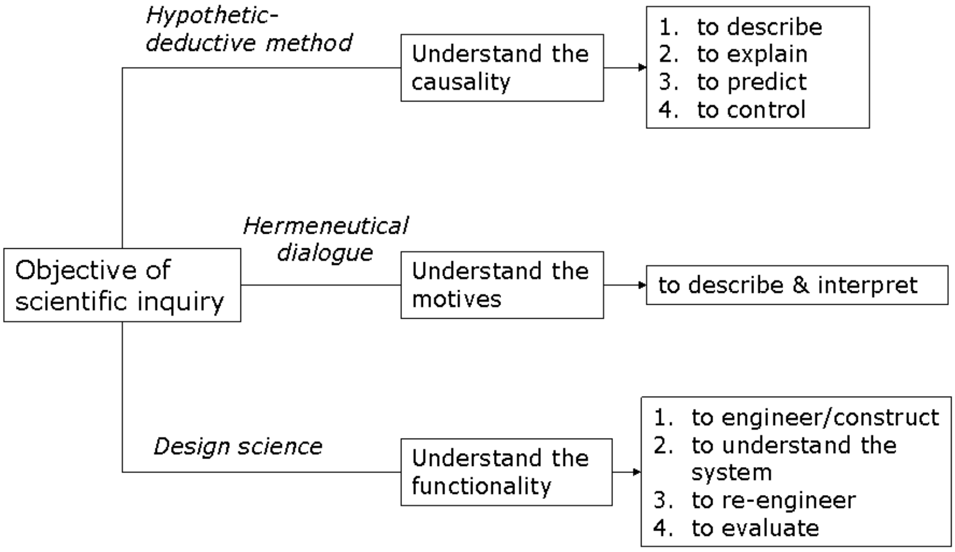

Figure 2. Different objectives of scientific inquiry

2.3. Scientific knowledge

The view of scientific knowledge as justified statements about the world is one of the cornerstones of the "traditional" view of science. Kiikeri and Ylikoski (2004, 21-24) describe this as the layman's view or common view of science, which contains many misunderstandings, oversimplifications and half-truths about science. According to the traditional view, science is characterised by objectivity, rationality and intellectuality, but the meaning of these terms remains often vague and ambiguous (ibid).

In philosophical discussion, the concept of justified statements about the world together with the characteristics of science becomes more complicated. Much of the discussion relates to the debate between the positions of scientific realism, and conversely, scientific anti-realism. In the view of scientific realism, the aim of science is to provide a true description of the world; hence, scientific knowledge ideally aims at the truth. Anti-realists, on the other hand, hold that true description can only be obtained from the observable part of the world, so the truth of the claims made of unobservable part of the world cannot be stated. Thus, the powers of observation set limits on scientific knowledge. (Okasha 2002, 59-60.)

This fundamental difference in thinking is reflected at least in the interpretation of concepts such as truth and fact. It also has resulted in debates on observability and related consequences, which in turn is connected with the understanding of the concept of theory. Another philosophical discussion strand around the same concepts is the empiricist-rationalist debate on the proper grounds for scientific knowledge. There still is an ongoing debate on what can be considered as true knowledge (realism versus anti-realism) and on how true knowledge can be obtained (empiricism versus rationalism).

2.3.1. Facts and truth

Factuality and truth are central characteristics of scientific knowledge for both traditional and multiple other views of science. Both are considerably more complicated issues than might be thought at first glance. The term *fact* refers simultaneously to a statement about an object and to the object itself. The factuality of a statement can be gained or lost, whereas the factuality of an object is thought to be independent of the statements and of the people making the statements. Also, scientific facts carry the dual meaning of the term. As statements, they are proven to be true via scientific inquiry, and are thus agreed upon as granting the status of a fact by the scientific community. Yet, in scientific discourse, one often hears that facts are "discovered" or that facts "are waiting to be discovered." In this sense, the fact often refers to the objects (even quite abstracts objects such as theories or phenomena) rather than statements. Nevertheless, the common understanding about facts is that they are presented in a form of explicit statements, which are somehow proven to be true. (Kiikeri & Ylikoski 2004, 219.)

Truth is a no less complicated issue. There are several philosophical theories concerning truth as well as an ongoing philosophical debate about it. The most famous theories about truth are correspondence theory, coherence theory, and pragmatist theory

(Haaparanta & Niiniluoto 1993, 19-20). According to correspondence theory, truth is the match between a thought or a sentence and a fact (note that here, the fact refers to the object). Thus, a sentence is true if the state of the affairs that it expresses prevails in real life. According to coherence theory, the truthfulness of a sentence depends on its compatibility with a group of other sentences. According to pragmatist theory, a sentence is true only if it enables us to act upon it. Haaparanta and Niiniluoto suggest that the most facile definition of truth both for our everyday thinking and science is provided by correspondence theory. Now, both factuality and truth have been defined, but only in reference to explicit propositional statements.

Both truth and factuality are concepts also used for demarcation purposes. Klemke (1998) introduces a classification whereby a distinction is made between law-finding sciences and fact-finding sciences, in which the subject matter of the former is said to consist of general laws and the subject matter of the latter of particular facts. According to Klemke, some people wish to limit the term *science* to denote only the law-finding sciences, where the term *fact* refers to statements only.

2.3.2. Observation, theory and phenomena

The bases for statements about the world have been a subject for philosophical debate for a long time. The early empiricists thought that all scientific knowledge was based on observations, and thus only legitimate statements about the world could be statements about observed qualities of the world. The critical positivists brought theories alongside the observations, but insisted that theories were just tools for describing observations and not explaining reality. The logical positivists agreed on two kinds of truths: formal, such as logic and mathematics; and empirical. For them, the purpose of empirical statements was to provide an empirical meaning for formal statements. (Sintonen 2002, Godfrey-Smith 2003.) According to Sintonen, the successors of logical positivists, the logical empiricists, said that observations could be explained by theories. They also acknowledged the problem of making completely objective observations and saw that theory can have an effect on making and interpreting observations. Godfrey-Smith perceives the history slightly differently and holds that the logical empirists also shared the empiricists' aversion to theories as descriptions of hidden or unobservable levels of structure.

The historical development presented above illustrates well the question of whether our scientific statements concern observations or theories. This question arises especially when the possibility of creating theories of non-observable objects (see e.g. Kiikeri & Ylikoski 2004 or Toulmin 1953) is discussed. One possibility for clarifying the issue is to bring a third element into the picture. Bogen and Woodward (see Kiikeri & Ylikoski 2004, 37-40) have made a conceptual distinction between data and phenomena. According to them, data provide evidence of a phenomenon. Consequently, theories explain phenomena, not data. A phenomenon is thus a stable and repeatable effect or process, which acts as a possible object for the scientific theory explaining or predicting it, and can therefore provide evidence to support the theory (ibid). Now the question about explaining or describing observations with theories becomes a question of finding data to describe a phenomenon and finding a theory to explain it.

Previously, theories were described as an explanation or a prediction related to certain phenomena. Gregor (2006) has examined the structural nature of theory in information systems and suggests a broader view of theory along with five distinct types of theory present in the knowledge base of information systems research. The first theory type in Gregor's taxonomy is the Theory for Analysing. These theories are descriptive and do not aim at specifying causal mechanisms or making predictions. The specified relationships among the examined phenomena are classificatory, compositional or associative; thus, the theories of this theory type are often referred to as *classification schemas*, *frameworks* or *taxonomies*. She suggests that this type of theory is valuable when little is known about the studied phenomena and when the created description is meaningful, natural, complete and exhaustive.

The second theory type in Gregor's taxonomy is the Theory for Explaining. These theories typically explain how and why some phenomena occur. Depending on the phenomena, the explanations can be either causal or teleological (see section 2.4.4 on explanation and understanding), but even when the explanations are causal, they do not aim at predicting. According to her, this type of theory is valuable when the insights provided are new or interesting and the arguments made are plausible, credible, consistent and transferable. (Ibid, 625.)

Just as all the theories for explaining do not allow for predicting, all the theories of predicting do not contain an explanation of the causal connections within the phenomena. This kind of theory, the Theory for Predicting, is the third theory type in Gregor's taxonomy. The theories of this type say what will be, but not why. The causal mechanisms may be omitted from these theories for three main reasons: 1) sometimes the causal mechanisms behind the phenomena are too difficult to be fully understood, as in the case of weather forecasting; 2) sometimes they are yet to de discovered; and 3) sometimes they are just not considered to be interesting or important. Although an understanding of the underlying causal mechanisms often allows for better prediction: if the practical importance of this theory type is high enough and the rigour of the methods sufficient, then the theories for predicting without providing explanations are valuable. (Ibid, 625-626.)

Gregor's taxonomy's type-four theory is the Theory for Explaining and Predicting (EP Theory). The EP Theory corresponds to commonly held views of theory in, for example, the natural and social sciences, and is well illustrated in the use of the term *theory* used in earlier text in section 2. The EP Theory provides predictions based on the understanding of the causes behind the phenomenon. The value and quality of this kind of theory is typically evaluated with measures such as validity, reliability, confirmability or credibility. (Ibid, 626-628.)

The fifth and final category in Gregor's taxonomy is the Theory for Design and Action. She describes this theory as being "about the principles of form and function, methods and justificatory theoretical knowledge that are used in the development of IS."

Although there are different opinions on whether or not this kind of knowledge should and could be called theory, the work of this type is an important part of information systems research. (Ibid, 628.) This theory type is discussed further in section 3.2.3, as it is perceived here to be an integral part of the knowledge base of engineering as well.

2.3.3. Non-propositional knowledge in science

Thus far, scientific knowledge has been equated with scientifically proven propositional facts, which can be either theoretical or empirical in nature. This is also the type of knowledge that epistemologists are interested in, as it carries information about the world (Lammenranta 1993, 72-75). Lammenranta distinguishes propositional knowledge from know-how, when know-how refers to our capability of doing something rather than our being able to tell others how something is done. Knowing how to ride a bike can mean either that one can explain how bike is ridden (propositional knowledge about riding a bike), or that one in fact can ride a bike (know-how about riding a bike). Lammenranta does not, however, take a stand on the informational value of know-how.

The presence of other knowledge types in science has been argued for by certain sociologists of science, such as Thomas Kuhn and Harry Collins. In his book *The Structure of Scientific Revolutions*, Kuhn (1996, 190) introduces the concept of paradigm. By paradigm, he refers to a certain scientific community's shared values and beliefs that are transmitted through the community and on to next generation via shared examples[1] of the solving of scientific problems in the field of that community. The educational power of shared examples lies, rather than in rules or laws, in the acquisition of consequential knowledge of nature through the similar relationship of physical situations. As a result, "That sort of learning is not acquired by exclusively verbal means. Rather it comes as one is given words together with concrete examples of how they function in use; nature and words are learned together. To borrow once more Michael Polanyi's useful phrase, what results from this process is 'tacit knowledge' which is learned by doing science rather than by acquiring rules for doing it." (Ibid, 191).

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[1] In the first editions of the book, Kuhn uses the term *paradigm* to refer to multiple different things. In later editions, as a response to criticism, Kuhn introduces the concept of the disciplinary matrix and defines the paradigm as the exemplars through which the disciplinary matrix is transmitted. (Kiikeri & Ylikoski 2004, 58-59). Still, the earlier, broader meaning for the term *paradigm* seems to be used more often; i.e., paradigm as the beliefs and values and the ways in which they are kept alive.

Collins (2001) applied Polanyi's idea of tacit knowledge to experimental science and suggested that it contains at least five kinds of knowledge:

1. Concealed knowledge: knowledge which is intentionally kept form others
2. Mismatched salience: researchers focus on certain of the indefinite potentially important variables in the experiment
3. Ostensive knowledge: knowledge which cannot be conveyed in words or pictures but must be understood by experiencing or feeling
4. Unrecognised knowledge: aspects that are performed without realisation of their importance
5. Uncognised/uncognisable knowledge: knowledge that is not understood or understandable at the level of brain functioning

He also noted that the conventional style of academic writing does not recognise the difficulty of experimental procedures and hence the importance of experimental skills.

2.4. Scientific inquiry

In the beginning of the 20th century, the very aim of science philosophers was to reconstruct the scientific method, with the help of logic (Kiikeri & Ylikoski 2004, 53). The view of this universal rational method was later challenged, but it is still strongly present in the traditional view of science (ibid, 22).

Much of the discussion concerning the philosophy of science still revolves around the methods of science. Okasha (2002, 11) states that analysis of the methods of enquiry used in different sciences is the principle task of the philosophy of science, and Godfrey-Smith (2003) suggests that the “scientific method” is what most people think of when talking about the general theory of science.

2.4.1. Discovery and justification

The classical definition of knowledge as a “justified, true belief” originates from Plato’s Theaitetos dialogue (see e.g. Haaparanta & Niiniluoto 1993, 18-19 or Lammenranta 1997, 79) When applied to scientific inquiry, the definition states that as the result of an inquiry, we have to come up with a statement (belief) which is true, and which we have good and rational reasons to believe in (i.e., not arriving at the statement merely by guessing or by taking the word of an authority). Thus, the belief has to be discovered and justified.

Although in principle the philosophy of science takes interest in the whole process of inquiry—creating statements and proving them to be true—focus has mainly been on the ways of accepting or rejecting a hypothesis (Haaparanta & Niiniluoto 1993, 55). The distinction between the concepts of discovery and justification was made by Hans Reichenbach (Godfrey-Smith 2003). It crystallised the early 20th century science philosophers’ dominant view that the formation of a hypothesis should be excluded from the logical analysis of scientific method (Kiikeri & Ylikoski 2004, 163.) Reichenbach separated the context of discovery from the context of justification and stated that the former is an object of psychological, sociological or historical analyses; only the latter may be an object of epistemology. In addition to that, Reichenbach stated that the object of the epistemological analysis is not the actual thinking process by which a scientist justifies his hypothesis, but rather the rational reconstruction of it. By the term *rational reconstruction*, Reichenbach meant the process of moving from premises to conclusions with logical, explicit steps. This idea of rational reconstruction can still be seen, for instance in the way most scientific articles are written. (Ibid, 163-168.)

In practice, the distinction between discovery and justification can be difficult to make. Giere (1984) points out that justifying a theoretical hypothesis requires that the hypothesis be the conclusion of an argument, with other statements as premises. In this case, finding the hypothesis is not solely about discovery, but also about logical argumentation; i.e., justification starting from the premises, once these have been discovered. The hypothesis to be tested is also often refined during the justification process, which then at some indefinite point becomes the discovery process of the refined hypothesis. Just as the discovery stage also includes rational or logical elements, the rational reconstruction is hardly a truthful description of the justification stage, which in actuality includes normative elements. These elements are constantly present in the paradigm, which guides the research process, including the justification. (Kiikeri & Ylikoski 2004, 165-166.)

2.4.2. Induction, deduction and abduction

Scientific reasoning can mean either the actual reasoning of scientists or the ideal reasoning (rational reconstruction) from the premises to conclusions (Haaparanta & Niiniluoto 1993, 53). In both cases, reasoning is thought to follow certain rules or forms of logic.

It is commonly stated that deduction is reasoning from general to particular and that induction is reasoning from particular to general. Haaparanta and Niiniluoto (1993, 56) consider this as a somewhat misleading statement, since it only applies to certain forms within deduction and induction. They prefer to state that reasoning is deductive when it adheres to the truth; i.e., the conclusion logically follows from the premises. Inductive reasoning, on the other hand, does not necessary adhere to the truth, but it may give us more information. Induction allows us to say something about a case based on another case (e.g., in making statistical generalisations). The price we have to pay is the possibility of making false generalisations. Deduction allows us to say something about a certain event, if we know that that something applies to all events. Now we can be sure that our statement is true, but it does not really increase our information about the subject. Only deduction can be fully expressed in the terms of formal logic. (Ibid.)

Peirce (see Habermas 1971, 113-114) distinguishes three forms of logic with respect to reasoning: deduction, induction and abduction. In his view "[d]eduction proves that something must behave in a certain manner, induction that something in fact does behave in certain manner, and abduction that something probably will behave in certain manner." Peirce sees abduction as the means to create new hypotheses by extending the content of our theories about reality to new situations. Induction is then used to check the agreement of our hypothesis with fact. Thus, abduction and induction are important to the logic of inquiry, whereas deduction is the least important logic for scientific progress, for we do not acquire any new information deductively. (Ibid.) This kind of reasoning has also been called explanatory induction, theoretical induction, theoretical inference, inference to best explanation and explanatory inference (Godfrey-Smith 2003).

2.4.3. The hypothetic-deductive method and hermeneutical dialogue

The hypothetic-deductive method is a form of scientific inquiry that begins with formulating a hypothesis and continues with testing it empirically. The hypothesis is typically a theoretical statement about a certain phenomenon. The empirical testing consists of creating a setting for and making observations about certain characteristics of the phenomenon under study. The data are said to confirm the hypothesis if the observations resemble what we had expected to observe as logical consequences of the hypothesis. If this is not the case, the data are said to prove the hypothesis incorrect, and the hypothesis must then be rejected. (Haaparanta & Niiniluoto 1993, 61-63.)

With the hypothetic-deductive method, the discovery of the hypothesis is excluded from the actual reasoning process. In this method, scientific reasoning commences from the hypothesis, and the observable consequences are derived from the hypothesis through the logic of deduction. Then a research setting is created to carry out tests and make observations, from which—through the logic of induction—the results either can or cannot be generalised to support or weaken the hypothesis. (Giere 1984.) According to Haaparanta and Niiniluoto (1993, 62), in the 20th century, the hypothetic-deductive method was the most important stance as regards the nature of scientific inquiry and scientific reasoning.

The process of inquiry in the arts and humanities has traditionally followed a different path of reasoning. The general method used for interpreting the meaning of a work of art or historical text is called a hermeneutical dialogue. In such a dialogue, the researcher proposes an interpretation for the meaning of the text (the objects of the research are generally called texts), and then applies this proposal to different parts of the text, simultaneously allowing the test parts to shape the proposal. In this manner, a researcher engages in a dialogue with the text. (Haaparanta & Niiniluoto 1993, 63-64; Taylor 1971.)

Hans-Georg Gadamer, one of the central developers of the hermeneutical ideas, opposed the whole idea of hermeneutics as a philosophical method. He stated that understanding is not a result of our conscious cognitive struggle, but rather something that happens in spite of it. To Gadamer, hermeneutics concerned describing the act of understanding and its requisites. (Kannisto 2002, 319-320.)

Haaparanta and Niiniluoto (1993, 66-69) argue that the process of reasoning in hermeneutical dialogue is not essentially different from hypothetic-deductive reasoning. The researcher creates a hypothesis for the interpretation and then tests this hypothesis against the text. If the proposed interpretation fits the text, the hypothesis has gained support; if it does not fit the text, a new hypothesis is created, as the former hypothesis is modified and then tested against the text. However, as Taylor (1971) points out, an outsider can be convinced of the interpretation only if s/he at some point shares the understanding of the language of the text in a similar way to the interpreter. If not, there is no basis for a shared rational argument. This appears quite different from hypothetic-deductive reasoning, which relies on the use of rational argumentation.

2.4.4. Explanation and understanding

Although the mechanisms of the hypothetic-deductive method and hermeneutic dialogue may appear alike, the aims of the inquiry processes employing these methods usually differ greatly. The hypothetic-deductive method is typically used for formulating empirically supported theories about causal relationships in natural phenomena, whereas hermeneutical dialogue is used for interpreting the meanings of certain occasions or understanding the human mind. In the history of science, the hypothetic-deductive method is closely related to the positivistic tradition, which has been especially influential in the realm of the natural sciences. Hermeneutical tradition is commonly followed in the humanities. The differences between these two traditions are vividly illustrated in C.P. Snow’s (1998) book *The Two Cultures,* but more from the cultural than from the philosophical point of view.

Von Wright (1971, 2-3) calls these two distinct traditions “Galilean” and “Aristotelian.” In his description, “the Galilean tradition in science runs parallel with the advance of the causal-mechanistic point of view in man’s efforts to explain and predict phenomena, the Aristotelian tradition with his efforts to make facts teleologically or finalistically understandable.” He suggests that the Galilean tradition aims at explaining and the Aristotelian tradition at understanding. This understanding is connected with intentionality, whereas causal explanation is not. Thus, understanding behaviour is to discover the objects of intention in it.

According to von Wright (1971, 83-85), the validity of a causal explanation depends upon the validity of the assumed nomic (i.e., law-like) tie between cause and effect, whereas the validity of the teleological explanation (i.e., understanding) does not. It implies that people may have intentions which are based on false beliefs, but these intentions nevertheless provide a valid teleological explanation for certain behaviour. Thus, for a teleological explanation to be valid, it is more important to obtain knowledge about a person’s interpretation of a situation than about the actual situation. Von Wright also distinguishes between the use of certain terminology and actual reasoning. He uses the term *quasi-teleological* for explanations which are expressed in teleological terminology, but whose validity depends on the truth of nomic connections.

He uses the term *quasi-causal* for explanations which are expressed in causal terminology, but whose validity does not depend on nomic connections.

These ideas about the difference between causal explanation and teleological understanding suggest that although the processes of reasoning in different traditions bear some resemblance, there are also disparities that need to be considered, at least when it comes to judging the validity and results of scientific research.

2.4.5. Theory-building methodologies

Sometimes a researcher’s scientific inquiry does not start with a preconceived theory and hypothesis; instead, s/he begins to collect data and lets the hypothesis and theory emerge from the data. This methodology of grounding theory and concepts in data was originally developed by Glaser and Strauss in the 1960s (Strauss & Corbin 1998, 9), and is nowadays known as grounded theory methodology. Since the 1960s, the ideas of grounded theory have developed and they have been combined together with other methodologies, such as that of the case study. The idea of starting with data rather than theory is also more generally called theory-building research (see e.g. Eisenhardt 1989).

Even though ideally theory-building research fully commences without a preconceived theory to be tested, Eisenhardt (1989) has argued that it can adopt a positivist view of research, in which the research process develops a testable hypothesis and thus creates a generalisable theory. However, it has also been used for giving rich and complex descriptions of specific cases (ibid). Thus, theory-building research also fits into the realm of hermeneutic inquiry.

Yin (1994, 3) states that each research strategy can be used for three different purposes: explanatory, explanatory and descriptive. Eisenhardt (1989) suggests that theory-building methodologies are particularly appropriate when only little is known about the phenomena and there is no previous literature or empirical evidence on which to base the study. Therefore, theory-building methodologies would seem to suit exploratory research best.

2.4.6. Quantitative versus qualitative inquiry

Research methods and methodologies are often divided into quantitative and qualitative. The differences between these two approaches are commonly described in terms of subjects discussed previously in this chapter. The traditional views of quantitative and qualitative approaches are presented in Table 1.

Table 1. Typical definitions of the differences between quantitative and qualitative research, adopted from Paavola (2003, 35)

Question	**Quantitative paradigm**	**Qualitative paradigm**
What is the nature of reality?	Realistic ontology: reality is objective and unequivocal and "outside" the researcher	Constructivist ontology: reality is subjective and equivocal and depends on the interpreter
What is the relationship between the researcher and the object of inquiry?	Endeavour for independence; the role of the researcher must be faded	Basis in interaction; researcher is an "instrument"
What is the role of values in inquiry?	Endeavour for value-neutrality and impartiality	Values and assumptions have to be presented
What is the process of inquiry like?	Deductive reasoning Theory-testing of a central issue Explanation Search for general and predictive facts	Inductive reasoning Theory-building of a central issue Understanding Understanding of the contextuality of knowledge

Paavola (2003, 36-37) states that while a strict separation of quantitative and qualitative research is arbitrary, there has to be some truth to the differentiation. However, the two extreme images of scientific inquiry created by this separation are equally false: the view of quantitative research as a totally objective and impartial quest for neutral facts is too naïve to be true. In addition, the perception of qualitative research as totally subjective and entirely dependent on the situation and interpreter and tightly tied to a certain set of values is something that no-one can recognise as his or her image of scientific research. In reality, scientific research, whether quantitative or qualitative, always operates somewhere in between these poles. (Ibid.)

Qualitative research is an approach embodying several different traditions which practice qualitative research in many different ways. Tuomi and Sarajärvi (2009) distinguish between the seven following traditions of qualitative research which differ not only in their use of research methods but also in their whole understanding of the nature and philosophical commitments of qualitative research:

1. Aristotelian tradition
2. Hermeneutic tradition
3. Phenomenological-hermeneutic tradition
4. Critical theory tradition and action research
5. Qualitative research tradition in the United States
6. Soft data tradition
7. Post-modern science

The term *methodology* has a fairly different status and meaning in different traditions. In the Aristotelian, hermeneutic and phenomenological-hermeneutic traditions, methodology is understood broadly as the entire basis of inquiry, including the ontological and epistemological assumptions and commitments. In these traditions, which emphasise understanding and interpretation, surfacing the researcher's pre-understanding of the knowledge, world, humans and phenomenon plays a more important role than the actual methods of data acquisition and analysis. However, in the American qualitative research tradition methodology, the ontology and epistemology of the research is seldom problematised, as the worldview in qualitative research is not necessarily perceived to be different than in quantitative research. In this tradition, the emphasis is on the methods of data collection and analysis (methodology in the more narrow sense of the word). (Ibid.)

Table 2. Different interpretive paradigms in qualitative research (Denzin & Lincoln 2003, Tuomi & Sarajärvi 2009)

Interpretive paradigm	**Positivist & postpositivist**	**Constructivist/ interpretive**	**Critical**	**Feminist poststructural**
Ontology	Realist or critical realist	Relativist	Materialist-relativist	Materialist-relativist
Epistemology	Objective	Subjectivist	Subjectivist	Subjectivist
Methodology	Experimental, quasi-experimental; rigorously defined	Naturalistic	Naturalistic	Naturalistic
Evaluation criteria	Internal and external validity, reliability, objectivity	Credibility, transferability, dependability, confirmability	Emancipatory implications	Emancipatory implications Reflexivity
Tuomi & Sarajärvi categorisation	American qualitative research*	Aristotelian Hermeneutic Phenomenological-hermeneutic	Critical theory & action research	Critical theory Soft data Post-modern science

*Although qualitative research in the United States undoubtedly is diverse in traditions, Tuomi & Sarajärvi's category seemingly refers to the models developed by some mid-20th-century qualitative research

From the North American perspective, Denzin and Lincoln (2003, 33-36) suggest that there are four major interpretive paradigms structuring qualitative research: positivist and postpositivist; constructivist/interpretive; critical (Marxist, emancipatory); and feminist poststructural. The ontological, empirical and methodological commitments of these paradigms are depicted in Table 2 together with a possible link to Tuomi and Sarajärvi's categories.

This diversity of traditions can be puzzling, especially to junior researchers. For example, in a situation where the researcher's philosophical commitments are in the hermeneutic style, but the methods are adopted from the positivistic tradition, s/he winds up in a situation where the ontological and epistemological assumptions and methodical choices are not in alignment with each other.

2.5. Norms in science

The code of conduct of the scientific community has been of interest in the sociology of science since the 1940s. The discussion started with Robert Merton's publications about the ethos of science, which according to him could be characterised via the following four universal norms: 1) *Communism*, or the common ownership of scientific discoveries and publicity of the results of science; 2) *Universalism*, or the evaluation of the claims to truth in terms of universal or impersonal criteria; 3) *Disinterestedness*, or the search for and publication of scientific knowledge selflessly regardless of one's personal interests or prestige; and 4) *Organised scepticism*, or the subjection of all ideas to rigorous, structured community scrutiny, delaying the making of conclusions until enough evidence is gained from empirical data. (Kiikeri & Ylikoski 2004, 110-113, Godfrey-Smith 2003.)

The four norms were not arrived at through empirical research, but in Merton's view, they could be derived from the purpose and methods of science with the objective of science being the expansion of verified knowledge. (Ibid.) The norms have later been amended to contain others such as originality, self-criticism and impartiality; and they are often referred as CUDOS (communalism, universalism, disinterestedness, originality, scepticism) norms (Kiikeri & Ylikoski 2004, 133).

Merton's norms have been studied extensively. Ian Mitroff conducted an empirical study on the realisation of norms in one particular scientific community and discovered that in reality, all of Merton's norms were challenged by counter-norms, which were accepted among the members of the community. The counter-norms consist of the following four items: 1) *Solitariness*, or keeping findings secret while the research is still in progress; 2) *Particularism*, or scientists' tendency to judge contributions to science by their personal knowledge of the researcher; 3) *Interestedness*, or the expectancy of selfish actions from colleagues when serving the interests of a researcher or research group; and 4) *Dogmatism*, or believing in one's premise (theory) being true and doubting the rival explanations. (Ibid, 124-126.)

Both Mitroff's and Merton's sets of norms can be shown to serve the scientists' interest in producing scientific knowledge. In fact, Kiikeri and Ylikoski (2004, 126) propose that both sets of norms could be united into a coherent whole by suggesting that Merton's norms describe the scientists' public behaviour and Mitroff's norms describe the "private stage" of research in progress. This would, however, require some modification to Merton's original theory. (Ibid.)

As a social activity, science is continuously changing. John Ziman has suggested that the CUDOS norms describe the ideal of science in the 1950s and 1960s well, but that technological and industrial development in society is transforming science towards a direction he calls "post-academic science." (Kiikeri & Ylikoski 2004, 133-136.) Post-academic science is, in Ziman's opinion, best described by the PLACE norms, explicated as follows, with science having the following five characteristics:

- Proprietary: not all knowledge is public, but parts of it are shielded by patents or other means. The ownership of the knowledge lies within companies rather than with researchers.
- Local: the aim of science is not so much the production of general knowledge anymore, but rather the finding of solutions to local practical problems.
- Authoritarian: research is done in large communities which are hierarchically managed.
- Commissioned: research is based on external commissions aiming at practical utility rather than the researcher's own intellectual interests.
- Expert-oriented: the role of the researcher is more that of a paid problem-solving expert than of a knowledge-creating individual.

According to Ziman, the CUDOS and PLACE norms cohabitate in contemporary science, but the PLACE norms are slowly replacing the CUDOS norms. This is due to many reasons, such as funding, and has both good and bad consequences. (Ibid.)

Kiikeri and Ylikoski (2004, 135) state that Ziman's view of post-academic science could easily be criticised for being too abstract, and they challenge Ziman's arguments by means of empirical research. It is, however, a fair attempt to conceptualize the change in science, and even though the concepts of academic and post-academic science are stereotypes, they reflect the challenges faced by science and the scientific community.

2.5.1. Aspects of quality

In practice, the scientific norms are reflected inter alia in the way the scientific community evaluates the quality of scientific knowledge and scientific work. Lincoln and Guba (1984, 289-301) define four questions of quality which scientific inquirers should pose to themselves. These questions are answered differently according to different traditions, bringing about different measures or criteria for quality. Table 3 introduces the four questions along with the answers from positivistic and naturalistic traditions (also known as interpretivist or constructive-interpretivist traditions).

Table 3. Four questions of quality with positivistic and naturalistic answers (Lincoln & Guba 1984, 289-301)

Question	**Positivistic answer**	**Naturalistic answer**
”Truth-value”: How can one establish confidence in the “truth” of the findings of a particular inquiry for the subjects with which and the context in which the inquiry was carried out?	Internal validity: The extent to which variations in a dependent variable can be attributed to controlled variation in an independent variable.	Credibility: The extent to which the interpretations of the researcher are credible to the respondents.
Applicability: How can one determine the extent to which the findings of a particular inquiry have applicability in other contexts or with other subjects?	External validity: The extent to which we infer that the presumed causal relationship can be generalised to and across alternate measures of the cause and effect and across different types of persons, settings and times.	Transferability: It is not the quality of knowledge but rather an empirical matter that depends on the degree of similarity between sending and receiving contexts—transferability inferences cannot be made by an investigator who only knows the sending context.
Consistency: How can one determine whether the findings of an inquiry would be repeated if the inquiry were replicated with the same/similar subject in the same/similar context?	Reliability: The extent to which each repetition of the application of the same, or supposedly equivalent, instruments to the same units will yield similar results.	Dependability: Consideration of the changes that occur in research setting. These can be due to either external changes in the context or they can be induced by the inquiry design.
Neutrality: How can one establish the degree to which the findings of an inquiry are determined by the subjects and conditions of the inquiry and not by the biases, motivations, interests, or perspectives of the inquirer?	Objectivity: The intersubjective agreement upon the methods and findings or the extent to which the study is rendered beyond contamina-a priori.	Confirmability: The extent to which the results of the inquiry can be corroborated by others.

Miles and Huberman (1994, 280) add a question of utility to the list of quality questions. In their opinion, the question of pragmatic validity cannot be avoided if the scientific inquiry is supposed to lead to more intelligent actions.

In Figure 3, the aspects and measures of quality are connected to the CUDOS norms of science (each underlined letter in the graphic below forms part of the CUDOS acronym). This exercise shows that in addition to the five questions mentioned above, the questions of novelty and publicity are relevant when the quality or “scientificity” or “scientificness” of knowledge is evaluated. It can also be seen that the question of utility is not reflected in the scientific norms in the same way as in the other questions.

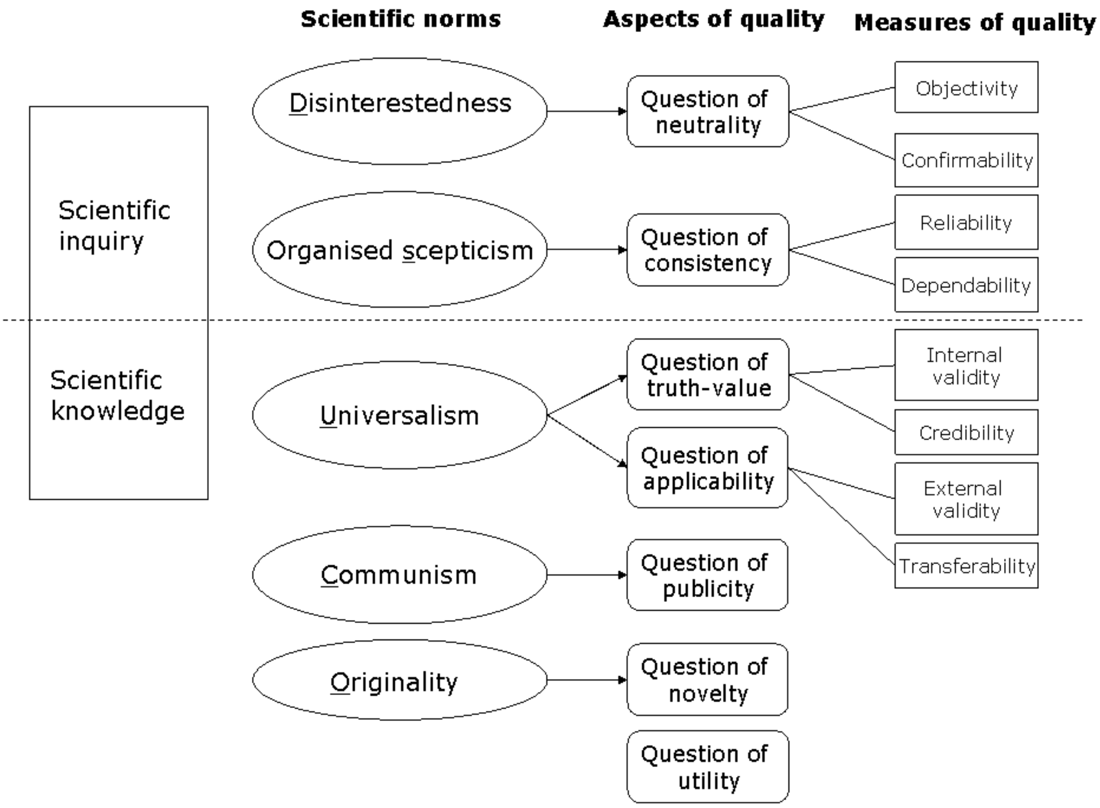

Figure 3. CUDOS norms and questions of quality in science

2.6. Design science

Design and science relate to each other in multiple ways. Cross (2001) distinguishes between scientific design, design science, science of design and design as a discipline. He suggests that scientific design refers to the modern design practice, where design is based on scientific knowledge and utilises a mix of intuitive and non-intuitive design methods. Design science, in Cross's terms, refers to a rational and systematic approach to design, which not only uses the scientific knowledge of artefacts but in some sense is a scientific activity in and of itself. He also states that this concept is controversial and challenged by many designers and design theorists.

Cross further suggests that the science of design refers to activities which improve our understanding of design through scientific methods of investigation. Finally, to him, design as a discipline means design studied on its own terms and within its own culture. Thus, design as a discipline seeks domain-independent knowledge of design, but through a process of inquiry that reflects the intellectual culture of design.

Design research began in the 1960s as a design methods movement (see e.g. Cross 2001, Glanville 1999). The desire of the movement was to base the design process on objectivity and rationality (Cross 2001). According to Glanville (1999), design in those days was not seen as a discipline in its own right, but as a defective science, which could (and should) be fixed by the proper application of scientific methods. The 1960s “design science decade” culminated with Simon’s suggestion for the doctrine about the design process, which is outlined in his book *The Sciences of the Artificial* (Simon 1969, third edition 1996).

Many designers seem to view design science as an attempt to gain respectability for design as an activity by forcing it into the mould of scientific research (Cross 2001). For Simon (1996, 111-114), the reason for developing the doctrine of design science was to get design back into the professional schools. In the 20th century, the natural sciences had almost driven out from the curricula of professional schools the sciences of the artificial; i.e., knowledge on how to design artefacts. The movement towards natural science proceeded the furthest and fastest in engineering, business and medicine. Simon perceived this development to have roots in the professional schools’ hankering for academic respectability. He stated, “The older kind of professional school did not know how to educate for professional design at an intellectual level appropriate to a university; the newer kind of school nearly abdicated responsibility for training in the core professional skills. Thus we were faced with a problem of devising a professional school that could attain two objectives simultaneously: education in both artificial and natural science at a high intellectual level.” (ibid, 113).

For the design science part of an engineering curriculum, Simon (1996, 134) proposes at a minimum the following seven topics:

1. The evaluation of designs: theory of evaluation (utility theory, statistical decision theory)
2. The evaluation of designs: computational methods (algorithms for choosing optimal alternatives, algorithms and heuristics for choosing satisfactory alternatives)
3. The formal logic of design: imperative and declarative logics
4. The search for alternatives: heuristic search (factorisation and means-ends analysis)
5. Allocation of resources for the search
6. Theory of structure and design organisation: hierarchic systems
7. Representation of design problems

Although Simon presents his ideas somewhat as a list of things to remember to introduce to young professionals, it undoubtedly also reveals something about his views on design activity itself. He suggests that, as for example computer programs describe complex design processes in a complete and detailed manner, the design process is not hiding anymore “behind the cloak of ‘judgment’ or ‘experience’” (ibid, 135).

In the 1970s, a general backlash against design science emerged as the result of both 1) the liberal cultural climate and the general rejection of conservative values and 2) a lack of observable success in the application of scientific methods to everyday design practice. However, in the field of engineering, design science and design methodology continued to develop strongly, resulting in a series of books on engineering methods and methodology in the 1980s. (Cross 2001.)

More recently, design science has been called forth as a new paradigm to complement the existing paradigms in particular fields. In March 2004, the Journal of Management Studies published an article by van Aken discussing the use of design science in management research. Likewise, in March 2004, Management Information Systems Quarterly published the article “Design Science in Information Systems Research” written by Hevner, March, Park and Ram. In both articles, the authors suggest that research in their discipline would benefit from acknowledging design science as a relevant research paradigm alongside the traditional behavioural or explanatory paradigm.

> *The main thesis of this article is that the relevance problem of academic management research can be mitigated if one would create space for Management Theory research, based on the paradigm of the design sciences, next to the more traditional Organization Theory research, based on the paradigm of explanatory sciences. As said, both research programmes can well operate in a profitable partnership. (van Aken 2004, 241)*
>
> *We argue that both design-science and behavioural-science paradigms are needed to ensure the relevance and effectiveness of IS research. Given the artificial nature of organizations and information systems that support them, the design-science paradigm can play a significant role in resolving the fundamental dilemmas that have plagued the IS research: rigor, relevance, discipline boundaries, behaviour, and technology. (Hevner et al. 2004, 98)*

Both articles also argue that in between the explanatory knowledge of phenomena and practical problem-solving, there is a significantly large area of knowledge related to constructing and evaluating solutions to problems in a certain application domain. This knowledge is neither general nor problem-specific. The task of design science is to produce this knowledge.

In the field of engineering, many of the aforementioned issues have been discussed under the heading “philosophy of engineering design.” Much of the discussion revolves around the nature of the engineering design process. Kroes (2009b) sees engineering design as an intrinsically different activity from scientific research, due to two specific features, namely the decisional nature of engineering design and the wide variety of constraints laid down for designers. The decisional nature is tied to the creation of new objects, and not to the discovery or representation of the pre-existing world as in the traditional view of science (ibid). This suggests that engineering design is not viewed as a paradigm complementary to scientific research in the field, but as a separate activity. However, there is an ongoing discussion about this issue (Kroes 2015).

2.6.1. Knowledge creation in design science

In the philosophy of science, the emphasis has been on the justification side of scientific inquiry. Discovery, on the other hand, has been a controversial topic among the philosophers of science, and is a slippery concept for philosophical analysis. Nevertheless, in recent years, philosophers have started to develop new conceptual models and tools for analysing processes of discovery. (Paavola 2001.)

In design activity, discovery plays a more important role than does justification, although a thorough evaluation of the end design against the relevant criteria is essential. Rust (2004) describes the relationship between discovery or invention, science and design in the following manner:

> *In the natural sciences, enquiry is concerned with uncovering or discovering that which exists. "Invention" is not considered to be a feature of scientific enquiry and perhaps is not compatible with the dispassionate relationship with knowledge that scientists traditionally have claimed. Design, by contrast, claims invention (and personal ownership of it) as a central principle, so it is difficult at first to see where the two traditions can overlap. (Rust 2004, 76)*

According to Simon's (1996) doctrine, the elements of discovery are especially present in activities related to the representation of design problems and the search for alternatives. In the extreme view, all problem-solving is equated with representing the problems in such as way as to make the solutions transparent. Even if this view seems too strong, it is evident that the way in which the design problem is perceived or defined has a remarkable effect on the whole design process.

The form of reasoning in the design process depends on the task at hand. Simon (1996, 115) discusses the need for a distinct logic of imperatives instead of the declarative logic used in scientific reasoning, but concludes that the requirements of design can be met by a modest adaptation to declarative logic and that a special logic of imperatives is thus unnecessary. The design process includes both reasoning from general to particular (deduction) and from particular to general (induction). Paavola (2006) has studied Peirce's abduction as a tool for conceptualizing the process of discovery or invention. Abduction is based on the claim that discovery is not about pure chance; instead, there are and must be some aspects which both constrain and instigate the search for new ideas. He suggests that "Peirce's broad philosophical system gives elements for an epistemological model which is a clear alternative to traditional empiricist and rationalist models" (ibid, 74).

Kroes (2009b) argues that analyses of scientific reasoning amount to variations of inductive, deductive or abductive forms, but that in designing, the means-end reasoning is the central form of thinking. Means-end reasoning is a form of practical reasoning. Hughes (2009) describes the process of means-end reasoning in engineering design as follows:

> *A purely instrumentalist account of engineering design begins with some ends given (i.e., final-in-context). The engineer then researches the problem thoroughly, so that he can identify a set of means that are relevant to its solution. Once these means are found, they become ends sought for the sake of original end. Again, research and existing knowledge are brought to bear to find appropriate means to realize these ends and so it goes until, at last, a design has emerged. (Hughes 2009)*

Hevner et al. (2004) perceive the research on information systems as a process consisting of two complementary phases: behavioural science explains or predicts the identified business need through the development and justification of theories; design science then meets the identified business need through building and evaluation of artefacts. (Ibid, 79-80.) According to this view, both paradigms include elements of discovery (development of theories, building of an artefact) and elements of justification (justification of theories, evaluation of artefacts). Yet, the methods are different, as the goal of behavioural science is truth, but the goal of design science is utility. In behavioural science, the methods are typically concerned with data collection and empirical analysis, whereas in the design science of information systems, computational and mathematical methods are of important use in evaluating the quality and effectiveness of an artefact, although empirical techniques may also be employed. In the interplay between construction and understanding, it is more important to determine whether an application works and in what kind of environments it works than to explain why it works. (Ibid.)

Van Aken (2004) perceives design science research objectives as tested and grounded technological rules. Thus, the creation of this kind of knowledge must include the processes of discovering this rule, by grounding it in scientific knowledge and testing its effectiveness. However, van Aken reminds us that basing a technological rule on explanatory laws does not always mean that every aspect of it is understood, but rather that several aspects may keep their “black box” character. This does not prevent the testing of the effectiveness of the technological rule (ibid). Again, it is more important to know whether something works than to know why it works.

Holmström, Ketokivi and Hameri (2009) view the knowledge creation process in design science for operations management quite similarly to van Aken, namely as a process whereby a solution is first created and then studied to develop a formal theory. They divide the research process into four phases: solution incubation, solution refinement, explanation I - substantive theory, and explanation II - formal theory. In certain ways, their requirements for testing the created solutions are even stricter that those of van Aken, as they are suggesting that ideally, design science research also yields a formal theory, which goes beyond the empirical context of the study. However, also according to them, the critical point in design science research is the ability to bridge phases two and three, and by doing this, increase the theoretical contribution in the development of practical problems as well as engage the developers of practical solutions in explanatory research testing of the solutions.

2.6.2. Norms in design science

In (natural) science, the results of scientific inquiry are descriptive statements which can be used to explain and predict phenomena. Design sciences aim at creating technological rules that express certain objectives and normative recommendations of action related to those objectives. Nowadays, the epistemic utilities of science (truth and information) are accompanied by a demand for relevance. This additional demand for practical utility then presupposes the evaluation of the process of inquiry and its results against some predefined rational criteria. (Niiniluoto 1985.)

According to Hevner et al. (2004), a design artefact is effective when it satisfies the requirements and constraints of the problem to be solved. Thus, the evaluation of an artefact requires a definition or appropriate metrics such as functionality, consistency, accuracy, performance, reliability and usability. Hevner et al. also state that the rigour of a construction activity must be assessed with respect to applicability and generalisability of the artefact, bearing in mind that an overemphasis on rigour can lessen the relevance. (Ibid, 88.) Van Aken (2004, 223) also acknowledges the rigour-relevance discussion, but suggests that instead of being about a dilemma where no satisfactory solutions exist, the question is about meeting criteria on both scholarly quality and managerial relevance.

Simon (1996, 29) distinguishes between optimisation and satisficing. Optimisation requires that all alternatives be measurable in terms of a common utility function. This rarely exists. Also, in finding a satisfactory alternative, some criteria of satisfaction are needed. Even in the case where optimisation is theoretically possible, it may not be practically relevant to look for the optimal solution, but rather to settle for the first acceptable option, as the search for alternatives takes up resources. (Ibid, 120.) The question becomes again that of balance between relevance and rigour.

In the light of CUDOS norms, the nature of design science and demand for utility and practical relevance seem most problematic with respect to the norm of universalism. As the objective of design science is not universal truth, the PLACE norm of locality may better suit both the practice and the idealistic objective of design science. The questions of communism, disinterestedness, originality and scepticism are not fundamentally problematic or incommensurable with the basis of design science, even though the mechanisms and criteria of evaluation differ from those of traditional science.

2.7. Summary

Chapter Two has introduced the basic philosophical concepts employed in this study. The notion of science has been discussed from the viewpoint of its purpose, the nature of scientific knowledge and scientific inquiry, and the values and norms generally related to it. It was noted that the term *science* has many different meanings. As a concept, its breadth can vary considerably: the narrow view of science includes results achieved by typically positivistic inquiry; the broad view encompasses the results, inquiry process, community and institutions related to different types of inquiries—positivistic, hermeneutical or design science. Naturally, the intended purpose of science varies according to the meaning of the word.

Scientific knowledge is often characterised by “fact” and “truth.” These are more complicated issues than may seem at first glance. Observation, theory and phenomena are also central, especially concerning scientific knowledge acquired empirically. The problematic behind these terms was discussed briefly as well as the propositionality and non-propositionality of scientific knowledge.

Scientific inquiry was discussed in relation with the actions of discovery and justification along with the different types of reasoning employed in these actions. The different approaches of the hypothetic-deductive method and hermeneutical dialogue were introduced, and the different aims—explanation and understanding—underpinning them were analysed briefly. Also, the possibility of theory-building methodologies was briefly explored. Lastly, the typically held views of and differences between quantitative and qualitative inquiry were discussed, with a special interest in the ontological, epistemological and methodological assumptions of the different paradigms.

The general values and norms behind science were introduced to shine light on the issue of quality. Quality was then discussed further by identifying different aspects of it and the different measures used to evaluate these aspects. Again, the subject was approached from the viewpoint of different scientific traditions, namely positivistic and naturalistic (also known as interpretivist) ones.

The chapter concluded with the introduction of the concept and tradition of design science. This began with an overview of the history of design science as a concept and a glance at various views of the relation of design science with the concept of scientific research. The general discussion about the nature of scientific inquiry was extended to include the design science tradition by presenting several ideas about knowledge creation in design science. Finally, the general discussion about the norms in science was also revisited from the perspective of design science.

The next chapter will use the concepts and knowledge from this chapter as tools of analysis. It will take us from the general world of science to somewhere more specific, namely the discipline of engineering and the realm of engineering science.

3. The philosophy of engineering and engineering science

> *During the 70s, I gave a lecture on the philosophy of science a couple of times to post-graduate engineering students in Helsinki, and once to the students of architecture in Oulu. I focused at the time on the contemporary topics in the philosophy of science: the scientific concepts, the requisites for usage of scientific laws and theories and the principles of scientific thinking. The subject seemed to be interesting to the audience, but I still had the feeling that the content of the lecture did not fulfil the expectations of that particular audience. I felt that something was wrong, but it was only much later during this decade that I realised, to my knowledge at least, where the fault lay. Instead of talking about the philosophy of science, I should have been talking about the philosophy of technology. (Free translation from Niiniluoto 1990, 64)*

Connecting the philosophy of science with engineering seems to require some adapters or connectors. There exists quite an extensive philosophical debate about the relationship between science and technology (see e.g. Bunge 1966, Mitcham & Schatzberg 2009, Radder 2009a&b, Houkes 2009, Hendricks et al. 2000, Poser 1998 and Niiniluoto 1990). Also, the connection between technology and engineering has been pondered upon (see e.g. Pitt 2000, Ihde 1997, Niiniluoto 1984a&b). Writing pertaining to the relationship between engineering and engineering science can be found, too (see e.g. Ropohl 1997, Eekels 2000, Eekels 2001).

Chapter Three brings these thoughts together in an attempt to form a more comprehensive picture of aspects that the philosophy of engineering science might contain, and thus sets the framework for what to seek in an empirical analysis. This chapter also points out topics having diverse lines of thinking and raises issues that are yet to be discussed, hence helping to identify the research gap.

3.1. The philosophy of technology

The term *philosophy of technology* (*Philosophie der Technik* in German) came into use at the end of 19th century among German engineers. At the time, members of the engineering profession started to create their own group identity and to understand the nature of their thinking and ways of doing science; this at a time when a fair amount of criticism was directed at technological development by some other groups in society. “Philosophy of technology” described the thinking of engineering professionals but also captured the idea of analysing the nature of and need for technological development. (Niiniluoto 1990, 64.)

The philosophy of technology finally entered academic circles around the 1960s. Niiniluoto (1990, 65) suggests that the breakthrough could be dated to 1966, when the journal Technology and Culture published a special issue called “Towards a Philosophy of Technology” and thus made the term recognisable also in English. Since then, interest in the field has grown steadily. (Ibid.)

Following Mitcham, Niiniluoto (1984b, 270) divides the work done in the area of philosophy of technology into three main approaches: 1) the analytic approach, which studies the conceptual and methodological problems related to technology; 2) the cultural-philosophical approach, which either criticises or defends the role of technology within the human life; and 3) the historical approach, which studies the conceptions of the nature of technology.

Olsen and Selinger (2007, iii-v) state that “philosophers of technology often go beyond merely trying to understand what technology is and how it transforms action, perception, and cognition. In many instances, an activist component is present: visions of good life are articulated, marginalized voices are represented and issues of participation and shared governance are explored.” As technological issues and problems are often complex in nature and broad in scope, the philosophy of technology has become an interdisciplinary enterprise, to which many scholars come from domains other than philosophy. (Ibid.) Along the same lines, Bunge (2007, 21) suggests that in addition to engineering, technology includes all the disciplines employed in the rational alteration of the reality.

Although both technology and the philosophy of technology may be considered to be interdisciplinary enterprises, Mitcham and Schatzberg (2009) argue that the meanings of terms such as *technology*, *engineering* and *engineering science* are strongly tied to the community discussing or studying these issues. Thus, the aforementioned terms may have different interpretations more within the context of science and engineering than, for example, in the contexts of humanities or social science. This implies that the philosophy of technology is dependent on the community and context in which it is practiced. (Ibid.)

3.1.1. Technology and science

Just like the term *science*, the term *technology* conveys multiple meanings. Mitcham and Schatzberg (2009) note that part of the problem in defining the term *technology* comes from the problems of translation into the English language. Most European languages, such as German or Finnish, use two separate terms that are both translated in English as technology. These terms originate from the Latin *technica* and *technologia*. The cognates of the latter usually refer to knowledge of the material arts, whereas the cognates of the former refer to the actual processes and methods of the practical activities pertaining to these arts. (Ibid.)

Radder (2009b) identifies two approaches for studying the relationship between technology and science: the conceptual-theoretical approach and the nominalistic-empirical approach (elaborated upon in the next paragraph). The conceptual-theoretical approach addresses the question of how to characterise science and technology through the specification of their aims. In tandem with this approach, it is often claimed that the aim of science is the acquisition of knowledge, and the aim of technology the construction of things with a socially useful function. (Ibid.) Houkes (2009) names this line of thinking “truth vs. usefulness intuition” (TU-intuition) (). This approach is problematic, as it presupposes specific philosophical interpretations about both science and technology, which are not generally acceptable (Radder 2009b).

Another option for approaching the question of the science-technology relationship is to define both as the practical activities they are. Radder (2009b) calls this approach “nominalistic-empirical,” and notes that it too is problematic, as any empirical identification of the science of technology requires pre-understanding and thus presupposes some conceptual-theoretical interpretation of the relationship. Although the two approaches are sometimes considered to be rival, Radder suggests that they be employed as a complementary process for articulating the conceptual interpretations which should be tested and backed up with empirical studies.

Niiniluoto (1990, 75-77) has derived from the literature six different views of the relationship between technology and science:

1. Technology and science as identical: technology and science are essentially the same; just two different names for the same line of action.
2. Technology and science as completely independent: technology and science are separate entities, which have no influence on each other.
3. Technology as subordinate to science: science is the primary activity and technology is derived from science.
4. Science as subordinate to technology: science is only one technological tool in the human interaction with nature.
5. Technology and science as originally disparate but nowadays combined: technology and science both have histories of their own, but are currently fused into technological science or scientific technology.
6. Technology and science as conceptually separate but constantly interacting: technology and science are historically different forms of human culture, which can interact with each other in many ways.

Radder (2009a) distinguishes between three different science-technology relationship models: 1) primacy models, which give primacy to either science or technology (compare with Niiniluoto’s views 3 and 4); 2) an interactive approach, which assumes the independent yet interacting nature of science and technology (compare with Niiniluoto 6); and 3) a seamless web idea where science and technology cannot be sensibly distinguished (compare with Niiniluoto 5). Gremmen (2013, 75) points out that in addition to seeing technology and science as different forms of culture, another prerequisite of the interactive approach is the acceptance of knowledge not having inherent implications. This means that it is not possible to trace a technological innovation backwards to a certain scientific discovery and make it thus a logical derivation of it, as the primacy model of science suggests (ibid).

In 1990, Niiniluoto stated that the conception prevails that technology is subordinate to science. This view is typically presented alongside the notion of technology as an applied science (Bunge 1966). In 2013, Ihde argued that "a modernist consensus regarding the sheer primacy of science over technology no longer holds for most contemporary thinkers" (ibid, 57). According to Radder (2009a, 25), the primacy model has been challenged by the interactive approach. Along with this comes the recognition that technology can be scientifically studied. Figure 4 outlines the different disciplines in which technology is studied.

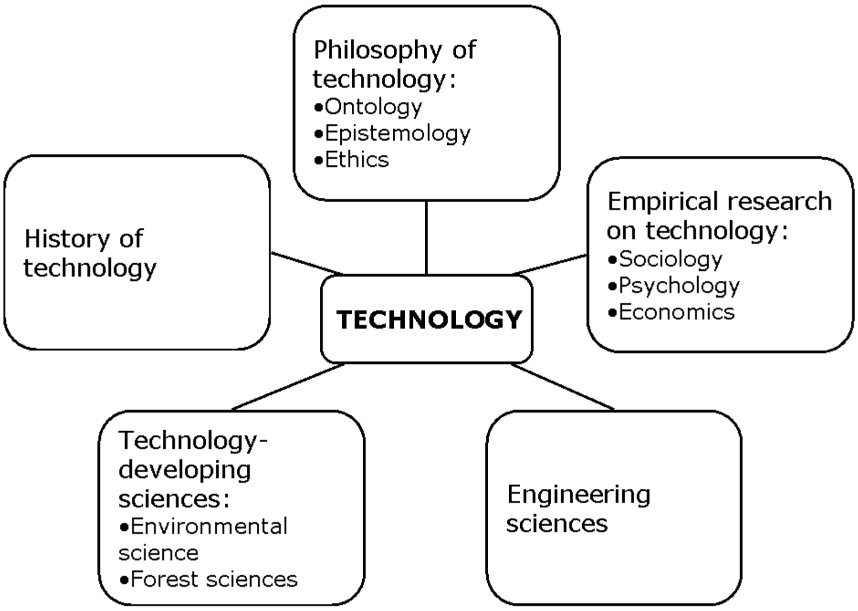

Figure 4. Different scientific disciplines studying technology (modified from Niiniluoto 1990, p. 69 figure 1)

Niiniluoto (1984a, 19) describes the technology-developing sciences as having originated as follows: “[A] Baconian marriage between science and technology gave birth to a class of ‘applied’ sciences in the 19th and early 20th century, when technological universities and laboratories of technological research started their operation.” Although engineering sciences are essentially also technology-developing sciences, Niiniluoto has placed them in the different box than the others. This may be to reflect the common view of engineering sciences being the discipline where science and technology unite.

Radder (2009b, 65) takes an even wider view towards technological science and holds that they “include several disciplines in addition to engineering sciences, such as information science, medical science, and agricultural science.” In any case, engineering sciences are a central part of technology and technical sciences, and will be discussed next in greater detail.

3.1.2. Engineering science

The Encyclopaedia Britannica from the year 1994 does not recognize the entry *engineering science* (Michelsen 2000, 626), nor does the Britannica online Encyclopaedia from the year 2014[2]. Still, there are probably hundreds of technical universities around the world teaching engineering and doing related research at the university level. The historical development of engineering sciences in Finland demonstrates that the discipline has emerged through the institutional organisation of education and research in engineering rather than having been grounded in a solid philosophical background.

There are several different stances as to whether engineering science is a natural science, an applied science, some other kind of science, or science at all. Pekkanen (2000) takes the stand that engineering science (or “technical science” as he calls it) belongs to the realm of natural science. In his view, technology is a part of the natural world or physical reality. Thus, the study of technology can be seen as a study of nature. According to Pekkanen, technical science pursues only epistemological and not practical utilities, and cannot thus be classified as an applied science.

Bunge (2007, 21) holds a completely different perspective–engineering is not considered to be science at all–from those espousing engineering science as a natural science. His view on this issue does seem to have changed over the course of time, since in 1966 Bunge equated technology with applied science and mentioned mechanical engineering as an example of the applied science division of physical technologies. To Bunge (2007), the core of any technological project is design. Thus, although modern engineering is certainly scientific as opposed to empirical, it is neither a basic nor an applied science, as its ultimate goal is to design artefacts, not to find truths. He also suggests that “when one realizes that every technology is a body of ideas, one understands that it belongs to culture along with mathematics, basic science, the humanities and art. In other words, technologists are intellectuals rather than craftsmen.” (Bunge 2007, 24).

To Niiniluoto (1990, 77), science is about finding information and truth; technology is about functionality and efficiency. In the intersection of science and technology lies an area where scientific methods are used to find knowledge that can be used for practical purposes. This area Niiniluoto calls “applied science.” In addition to the use of scientific methods and knowledge, applied science can also systematize the experiences of the users and developers of technology. Engineering science is one example of these applied sciences. Niiniluoto’s view differs from Pekkanen’s view in that he sees engineering science pursuing both epistemological and practical utilities. Unlike Pekkanen, he also considers the experiences of people working with technology as a legitimate object of study in engineering science. In this respect, Niiniluoto’s view of applied sciences in general may be wider than the often used definition of applied

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[2] most recently verified on 3 October 2014

sciences, which is simply the application of the results of basic sciences for practical purposes.

Bucciarelli (2013, 66-69) suggests that engineering science is distinguishable from ordinary science in its ability to alter the object under study. This malleability of research objects results in different interpretations of many concepts central to natural science, such as objectivity, truth and reality. Yet, Bucciarelli sees engineering science more as science than as engineering practice. He justifies this view with 1) the different degree requirements for doing engineering science and practising engineering; 2) the different degree of controllability of the use of the products; and 3) the multi-paradigmatic nature of engineering problem-solving versus the single paradigm presence in engineering science research. In using the term *paradigm*, Bucciarelli seems to be referring to domains of knowledge affecting the inquiry process simultaneously.

Kroes (2009a) distinguishes between typical engineering research problems (e.g., determining whether a given construction fulfils certain criteria) and typical engineering design problems (e.g., finding a construction that satisfies a list of requirements). This suggests that engineering science research and engineering design are variant, mutually exclusive activities. It also deprives engineering science from the malleability described by Bucciarelli by placing it on the engineering design side. If, however, engineering science is understood as the process and results of all inquiry processes reported as scientific research in technical universities, the concepts of engineering science research and engineering design may in real life overlap with some of the scientific inquiry solving determination problems and some solving construction problems.

From the viewpoint of the historical development of engineering sciences in Finland, Michelsen (2000, 627) suggests that engineering sciences have no epistemology of their own, but that their theoretical structure is linked to the changes in natural sciences and technology. The historical invisibility of epistemology in engineering science does not necessary imply its absence or impossibility. Hendricks et al. (2000) state that “engineering science is a scientific discipline that from the point of view of epistemology and philosophy of science has been somewhat neglected.” They claim that the consensus nowadays seems to be that engineering science is an enterprise of its own science governed by its own epistemology, methodology and ontology. While it shares some basis with pure and applied sciences, it features its own methodology and creates its own body of knowledge. Hendricks et al. support this view by providing a systematic analysis of the research profiles in pure science, applied science and engineering science. They note as well that each profile “admits” a certain set of research objectives, epistemic assumptions, methods and values.

3.1.3. Coherence and diversity in engineering science

Previously, the term *engineering science* has been discussed as a singular noun. According to Mitcham and Schatzberg (2009, 42) this can legitimately be done, although the term is often used in the plural (*engineering sciences*). The use of both forms, singular and plural, suggests that the discipline entails questions regarding the coherency and diversity of the field.

Banse and Grunwald (2009) suggest that although technical systems represent enormous diversity, the ways in which they are developed and applied involve uniform features and elements. According to them, all engineering sciences are target-oriented, have a constructive character; and integrate knowledge from natural sciences, other technical sciences and the social sciences. This coherence extends to both process (methods) and products (substance) of engineering sciences.

The strong common features of the methods in engineering sciences are connected to the theory-practice relationship of the field. Banse and Grunwald (2009) classify the methods of the engineering sciences into methods of design (intuitive-heuristic or rational-systematic), methods of research (theoretical-deductive or empirical inductive) and methods of implementation (various different approaches). The knowledge produced by these methods takes the form of technical rules, although the concrete forms of these rules may show great diversity. In addition, the basic phases of technical design are perceived to be coherent across the engineering sciences (ibid).

The results of a technical design have to fulfil not only the technical requirements but also the non-technical or external requirements, such as demands for social or economic success. Banse and Grunwald also state that the significance of the external side of technical solutions has increased significantly over the last years. They state, that "[t]he specific relationship between theory and practice in the engineering sciences entails concern not only with technical matters but also with the social context. This places methodological requirements on methods of selection and evaluation whilst also underlining the specific responsibility of the engineering sciences. This is a necessity that is shared by all the disciplines in the engineering sciences." This makes matters such as anticipating user behaviour and considering adverse consequences become general methodological requirements in engineering sciences. (Ibid, 174-175.) They note, however, that the application of the methodology to answer these requirement takes different forms in the different engineering science disciplines.

All this seems to suggest that the very basic issues related to objectives, methods, results and quality issues concerning different areas of engineering science are coherent enough to call engineering science a unified discipline. Nevertheless, the practical realisations of these issues may show great diversity according to the matter at hand.

3.2. Knowledge in technology and engineering

Knowledge concerning technology is manifold. The word *technology* originates from the Greek word *tekhne*, which translates into the English word *art*. In its broadest sense, technology could be understood as any art of human activity, especially the design and usage of aid items needed for performing the art. The meaning has been subsequently narrowed down to signify the design and making of artefacts. However, for an engineer, even this characterisation of technology may be too broad. Technology for engineers commonly denotes the design and making of equipment which is efficient and functioning in relation to a certain mechanistic purpose. (Niiniluoto 1990, 74.) Thus, for example, the aesthetic qualities of an artefact are seldom of concern to engineers.

According to Houkes (2009), most of the discussion around the nature of technological knowledge or epistemology of engineering science contains an objective of epistemological emancipation. The idea of epistemological emancipation involves the thought that scientific and technological practices result in bodies of knowledge that are distinct in the sense that there are no ways of incorporating one body of knowledge into the other. According to Houkes (2009, 311), this emancipation is usually pursued through the following four strategies: 1) contrasting scientific and technological knowledge directly, 2) constructing taxonomies of technological knowledge, 3) appealing to the tacit nature of technological knowledge, and 4) appealing to the prescriptive nature of technological knowledge.

Although this study is not aiming at epistemological emancipation, as its objective is to understand engineering science per se and primarily not in comparison with natural science, much of the discussion that follows can be tracked back to the strategies mentioned above. In Houkes' opinion, the issue with the emancipatory strategies is that they often compare technological knowledge to an unrealistic view of scientific knowledge. This likely cannot be totally avoided here, either. Nevertheless, the subject of technological and engineering science knowledge is studied because, as Houkes also agrees, even if there is no need for epistemological emancipation, there still is a need for a better understanding of the epistemology of technology and engineering science.

3.2.1. Levels of technological knowledge

As noted earlier, the term *technology* in English language is far from concise. According to Ropohl (1997), it commonly encompasses not only the practice and results of engineering but also scientific research on engineering. To clarify the matter, Ropohl proposes the word t*echnics* to denote the field of engineering work and its products, and the word *technology* to denote the science of technics. Accordingly, he uses the phrase *technical knowledge* to refer to the knowledge applied to the engineering practice, and the phrase *technological knowledge* to refer to the knowledge applied to engineering science. Thus, Ropohl's definition for technological knowledge is much more concise than the term as it is commonly used.

To extend Ropohl's characterisation to include the layman's knowledge of technology, and not just that of the engineer, the term *engineering knowledge* could be used instead of the term *technical knowledge*, and the term *engineering science knowledge* instead of the term *technological knowledge*. Then the term *technology knowledge* could be used in the broad sense to refer to any knowledge referring to the technological world. This conceptualisation is illustrated in Figure 5, and it also compasses the idea of engineering knowledge and engineering science knowledge intersecting in such a way that there is a body of knowledge common to both areas, but that both these areas additionally contain some knowledge which does not belong to the realm of the other. In other words, there is engineering knowledge, which cannot be called engineering science knowledge, but there also is engineering science knowledge, which is not directly applicable to engineering work.

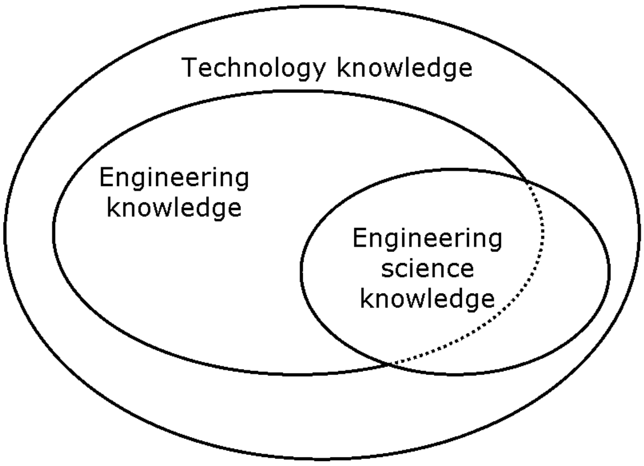

Figure 5. Technology knowledge, engineering knowledge and engineering science knowledge

Eekels (2000) also differentiates between engineering knowledge and engineering science knowledge, which he calls “engineering design science.” His stratification around engineering design science consists of five levels which stand in meta-position to each other. Eekels’s stratification of engineering design science is presented in Figure 6.

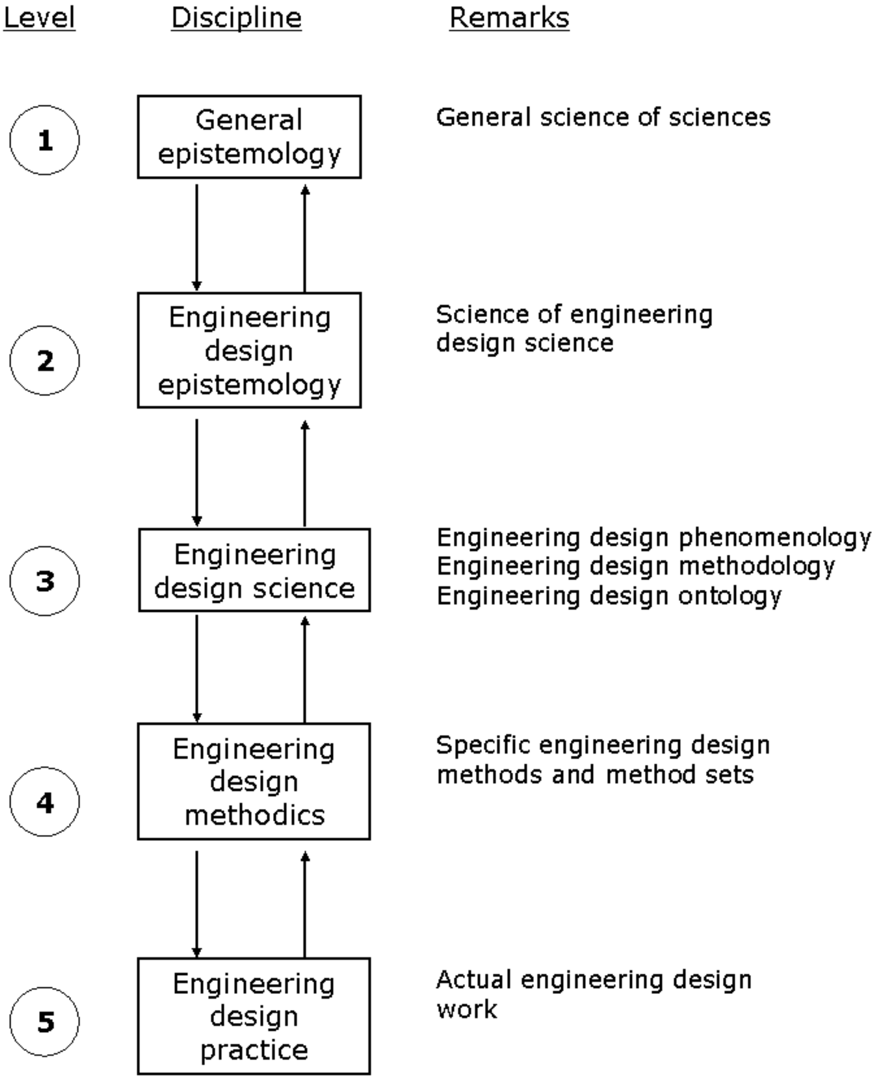

Figure 6. The stratification of engineering design science (Eekels 2000, Figure 3)

The fifth (and lowest) level of this stratification, engineering design practice, refers to the knowledge engineers use and produce while solving design problems. At this level, creativity and intuition have important roles, and the design takes place in a certain framework according to a methodical approach.

The fourth level, engineering design methodics, consists of the whole body of the engineering design methods and the systems of these methods. These cannot be considered as scientific knowledge, but they can be objects of scientific investigation.

The third level is engineering design science. Eekels often calls this level "engineering design science proper," so as to clearly distinguish it from both the first and second levels, which are more practical than scientific; and the fourth and fifth levels, which are more philosophical than scientific in nature. Knowledge at the level of engineering design science is created through the scientific study of engineering design practice and engineering design methodics.

The second level is engineering design epistemology. This level studies the fundamentals of engineering design science from philosophical, and more particularly from epistemological, standpoints. As he suspects that using the term philosophy "may evoke controversial attitudes" (Eekels 2000, 382), he does not call the level "philosophy of engineering design science," but the meaning is essentially the same.

The first level of knowledge in this area is also philosophical but more general in nature. It is the level of general epistemology, which studies the questions of knowledge and knowing in all scientific disciplines.

3.2.2. Types of technological knowledge

Most of the classifications or typologies comprised of technological knowledge actually refer to engineering knowledge. Ihde (1997, 73), however, has approached the subject from a wider perspective. He divides technology knowledge into three dimensions: 1) knowledge about technologies, which reflects the engineer's knowledge about how a machine is made and how it functions. This dimension thus resembles engineering knowledge; 2) theoretical technology knowledge, which is the knowledge of laws and principles which allow certain technology the capacity to do what it does; (Ibid.) This could be included in engineering science knowledge; and 3) knowledge though technologies, which is more general in nature and runs through a wide range of human actions and implies that technologies transform the way human see the world and themselves in it. (Ibid.) Technology is not only an object of knowing but also actively involved in the process of knowing and acquiring knowledge.

Bunge (1966) approaches the issue from another angle, but his scope of technological knowledge is also wider than mere engineering. He suggests that technological knowledge is created as a result of applying the scientific method to practical problems. This knowledge consists of technological theories, technological rules and empirical data. Technological theories can be substantive or operative. Substantive theories provide knowledge about the objects of action, such as machines. These theories are derived from scientific theories. Operative theories provide knowledge about the action itself. Operative theories do not employ scientific theories, but rather the method of science. Thus, they have to be empirically testable with reasonable control over the relevant variables.

A technological rule indicates how a certain predetermined goal can be achieved. It is distinguishable from "rules of thumb" through basing it on a set of scientific laws accounting for its effectiveness. The grounds of the rule explain why the rule is effective. According to Bunge (1966), the development of modern technology is the result of both transforming the scientific laws into technological rules and finding scientific grounds for the practical rules employed in prescientific arts and crafts. Technological rules are used in practice by practitioners such as technicians. This should, however, not be taken as empirical testing of the rules, because the estimation of truths value of technological theories and efficiency of technological rules can only be done by pure and applied research alone, hence by the scientific method. (Ibid.)

McCormick (1997) discusses the nature of technological knowledge with respect to technology education and hence engineering knowledge. He distinguishes between procedural ("know-how") and conceptual ("know-that") knowledge, but emphasises that conceptual knowledge is not just a collection of inert facts, but also consists of ideas formed by concepts and their relationships. Within the category of procedural knowledge, McGormick brings up the notion of strategic knowledge as a kind of controlling knowledge ("how-to-decide-what-to-do-and-when" knowledge). In engineering, he perceives two kinds of conceptual knowledge: the knowledge drawn from another subject, such as science; and the knowledge unique to technology (engineering). (Ibid, 153.)

Quite similar to the previous typology is Venselaar's division of knowledge into declarative, procedural, situational and strategic knowledge (see Ahmed et al. 2005 for Venselaar 1987). Declarative knowledge contains the facts and principles in a particular domain, procedural knowledge is about how to undertake a certain action, situational knowledge is about understanding the context in which knowledge is applied and strategic knowledge is the knowledge of processes facilitating the acquisition and utilisation of knowledge. (Ibid.)

Not all knowledge in technology can be expressed in propositions. When propositions can be used, not all follow the type of those used in science, namely propositions referring to actual state of affairs. (de Vries 2005.) De Vries (2005) identifies four types of propositional knowledge in technology: 1) functional nature knowledge, where X knows that carrying out certain action will result in a certain change in state of affairs; 2) physical nature knowledge, where X knows that a certain artefact has certain physical properties; 3) knowledge of the relationship between physical and functional nature, where W knows that a certain artefact has certain physical properties and that this makes it suitable for carrying out certain action which will result in a certain change in state of affairs; and 4) process knowledge, where X knows that the (intended) change in state of affairs can be realised via using a certain artefact for carrying out certain action. The second proposition, physical nature knowledge, is similar to propositions in natural sciences, but the first, third and fourth types of propositions have a normative component that knowledge in natural sciences does not have. (Ibid.)

Ropohl (1997) has derived following five knowledge types based on his systems theory of technics:

1. Technological laws
2. Functional rules
3. Structural rules
4. Technical know-how
5. Socio-technical understanding

Technological laws are systematisations of theoretical knowledge which can be derived from natural laws. Sometimes technological laws have no scientific grounds as they are solely empirical generalisations. Technological laws are then transformed into functional rules, which specify what to do in order to attain certain results under given circumstances. Structural rules concern the assembly and interplay of components of a technical system. They may have a scientific background, but sometimes they originate from traditional and current experience only. Technical know-how refers to the skill of designing. It is largely implicit and often includes unconscious use of cognitive resources such as images, reminiscences, experiences and intuitions. Socio-technical understanding is knowledge about the ecological and psycho-social context in which the technology is located. As "every invention is an intervention" (ibid, 71) engineers also need to reflect upon the preconditions and consequences of their work.

Studying different aspects of engineering work and knowledge through a historical case studies in aeronautics, Vincenti (1990, 208-222) proposes the following categorisation of engineering knowledge:

1. Fundamental design concepts
    - Operational principle
    - Normal configuration
2. Criteria and specifications
3. Theoretical tools
    - Mathematical methods and theories
    - Intellectual concepts
4. Quantitative data
5. Practical considerations
6. Design instrumentalities
    - Structured procedures
    - Ways of thinking
    - Judgmental skills

Point one, fundamental design concepts, involves the very basic assumptions the designer brings to the setting. Operational principle is the essence of why the device works as it does. It provides the criterion of success or failure in technical sense and, in effect, defines a device. Normal configuration is the general shape and arrangement that are commonly agreed to embody the operational principle the best. According to Vincenti's terms, design is normal when it follows the operational principle and normal configuration of similar devices. Radical design involves a change in normal configuration and possibly also in operational principle.

Pertaining to point two, criteria and specifications, translation of utilitarian goals of a device into concrete technical terms requires a decision on the technical specifications of the device and creation of criteria to measure the attainment of those specifications. This implies assignment of quantitative values or limits to those criteria. Both the knowledge about criteria and specifications in a particular design task, and the knowledge on how the specifications and criteria are obtained are crucial for engineering design.

Point three, theoretical tools, includes the mathematical methods and theories applied in the process of design and the concepts around which the design evolves. The intellectual concepts may be called the professional vocabulary of a specific field of design. Mathematical tools range from purely mathematical to purely empirical methods of quantifying concepts and phenomena and operating on them. They may also contain physical laws and theories, engineering theories and device-specific heuristics, depending on the design problem. Theoretical tools are accompanied by point four's quantitative data, usually obtained empirically.

Point five, practical considerations, refers to considerations derived from practical experience. These are often hard to find written down, as they tend to be stored in the minds of designers, usually on an unconscious level to some degree. Practical considerations often take the form of "rule of thumb." Similarly, design instrumentalities which are often called know-how or procedural knowledge are partially unconscious. Vincenti views this know-how as consisting of structured procedures, such as dividing the system into subsystems or using certain optimising or satisficing procedures; mental processes, such as creating mental models and anticipating effects of alterations based on them; and judgmental skills for seeking out solutions and making design decisions applying visual thinking, imagination and intuition. Judgmental skills include the ability to weigh technical considerations against the demands of the social context.

Vincenti's (1990) and Ropohl's (1997) characterisations have a good deal in common. Ropohl's technological laws and functional rules contain very similar aspects to Vincenti's theoretical tools and quantitative data. Both suggest that scientific laws are quite seldom useful as such to engineers, but they are transferred to technological laws and engineering theories which are more case-specific and may include empirically obtained elements to complement them. Likewise, there seems to be a strong connection between Ropohl's structural rules and Vincenti's fundamental design concepts, both of which emphasize the importance of having knowledge on the general principles governing the functioning of a technical system. Also, the categories of technical know-how and characterisations of practical considerations share considerable common ground, which partly extends to the structured procedures and ways of thinking in Vincenti's design instrumentalities. Lastly, the socio-technical understanding of Ropohl's typology is present also in Vincenti's judgment skills, leaving only Vincenti's criteria and specifications without an obvious counterpart from Ropohl. As it regards the finding of a technical solution to utilitarian needs, it at least partly deals with socio-technical understanding.

Table 4 summarises the typologies presented above. They fall quite well into four categories, where the more common knowledge characterisation, "know-that," a collection or construction of explicit facts; and "know-how," an ability to perform certain action, are complemented by "know-what" and "know-why" types of knowledge.

Table 4. Different types of knowledge in engineering —interrelations of some typologies of engineering knowledge

	Know-that	**Know-how**	**Know-what**	**Know-why**
McGormick & Venselaar	Declarative / conceptual knowledge	Procedural knowledge Strategic knowledge		Situational knowledge
de Vries	Functional nature knowledge Physical nature knowledge	Process knowledge	Knowledge of the relationship between physical and functional nature	
Ropohl	Technological laws Functional rules	Technical know-how	Structural rules	Socio-technical understanding
Vincenti	Theoretical tools Quantitative data	Practical considerations Design instrumentalities: structured procedures & ways of thinking	Fundamental design concepts (operational principle & normal configuration)	Design instrumentalities: judgmental skills

Know-what knowledge is probably best characterised by Vincenti's idea of fundamental design concepts, which are often implicitly or tacitly owned ideas of functionality that define the essence of certain technology. Know-why knowledge refers to the thought that every invention is an intervention in society, and that engineers ought to possess sufficient knowledge about the needs of and consequences for mankind in relation to the technologies they are developing.

3.2.3. Knowledge in engineering science

Thinking about the basis and nature of technology knowledge is an important part of the thinking about the epistemology of engineering science, but that alone is not sufficient. Eekels (2000 & 2001) defines engineering design science as the scientific study of engineering design. Following a general interaction model of action, he goes into more detail in describing different areas of study in engineering design science.

In the general interaction model of action, a change is produced by an action subject interacting through an action process on an action object. An action subject can be an individual or a collective actor, who or which has both a material and functional organisation. The material organisation of an actor defines the different parts of the actor, whereas the functional organisation defines the duties of different parts related to the action process. Thus, entities having a similar material organisation can have a very different functional organisation, and vice versa. The action process starts with the observation and evaluation of the present state. A decision to intervene into the situation is made together with the definition about the purpose of intervention. This purpose design is then followed by a means design, and finally by the material realisation of the means design; that is, the execution of the intervention. The action object is "an entity that is seized upon by the actor at the start of his action, and which subsequently transforms into the intended stage” (Eekels 2001, 255). According to Eekels, engineering design is information processing, and thus the object of engineering design is always information about something. As engineering design is always at some level intended for the use or service of mankind, the information about the needs and values of the stakeholders of the engineering design is inherent in the action object of the engineering design.

Eekels proposes several topics to be studied by engineering design science. These are presented in Table 5. In addition to the objects of possible inquiry relating to the general interaction model of action in engineering design, Eekels also states that the ontology (philosophy of being) of engineering design may not be neglected from the standpoint of engineering design science. Among the interesting ontological questions are questions such as “Where do ideas for new products come from?” and “How is simulation possible?” (Eekels 2001, 274).

Table 5. What should be studied in engineering design science proper, according to Eekels (2000 & 2001)

Aspect of action	**Objects of inquiry**
Action subject – Material organisation – Functional organisation	Reasoning patterns needed and used by the designer (rationality) Decision theory Values, norms and other criteria in design decisions (axiology) Duties of designers in the light of morality (deontology) Coordination of multiple reasoning processes and decision-making in complex action subjects Coordination of multidisciplinarity in design projects
Action process – Observation of the present state – Evaluation of the present state – Decision to intervene – Purpose design – Means design – Material realisation	Essential structures of the main engineering design phenomena (phenomenology): Action-making processes Industrial innovation process Hierarchy of industrial design processes Product and process design Industrial new business development Industrial product planning Engineering design methodics (the whole body of engineering design methods and systems of methods) Descriptive engineering design methodology Prescriptive engineering design methodology
Action object – Information – Information referents (stakeholders)	Theory of technical systems Scientific laws and theories relevant to engineering design Stakeholder analysis Ecological aspects of engineering design Information on laws, norms and standards pertaining to the design project in question

Gregor and Jones (2007) conceptualise the phenomena of interest for design research a bit differently, but with many similar elements included. In their analysis of the relationships among information systems artefacts, they separate the material artefacts from the abstract ones, which they name theories; and from the human subjective understanding of both types of artefacts. Material artefacts include instantiated products, such as a database, but also instantiated methods; i.e., the series of physical actions done when implementing the method in the material world. Theories are typically constructs, models and methods which do not have a material instantiation but are expressed by some other means of representation such as words, pictures or diagrams. According to Gregor and Jones's (2007, 321-322) definition, "A theory can be about both the principles underlying the form of the design and also about the act of implementing the design in the real world (an intervention)." Thus, a technical product and its building process are material artefacts, whereas the design principles of both the product and its building process are artificial artefacts, which Gregor and Jones call "design theories."

Expansion upon Gregor's and Jones' line of thinking to include the conceptualisation of engineering design research is what is presented in Figure 7. The division of artefacts into material and abstract categories is also surely possible within engineering products and processes. Similarly, human subjective understanding is also present, as the artefacts are created and used by humans. Some of the material artefacts in engineering are instantiated products or process/method designs, just as in information systems.

However, engineering products and processes sometimes hail back to an older tradition; i.e., they are crafted rather than designed, and sometimes they are used in a manner that is quite different from the intention of the original design. Thus, in the engineering design, this suggests that the material artefacts are not always created from the design theories, but that design theories can be created from the study of material artefacts. This is particularly reflected in the three research objectives comprising understanding the systems, evaluation and re-engineering (see Figure 2 on page 13).

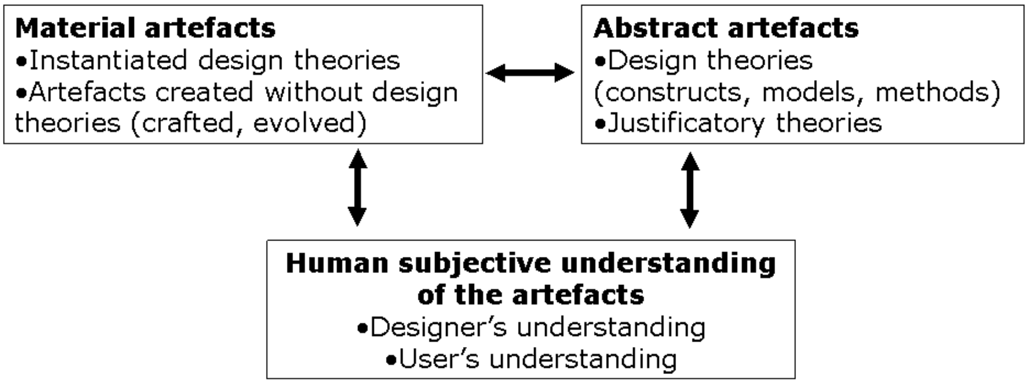

Figure 7. The relationship between artefacts in engineering design research, adopted and modified from Gregor & Jones's (2007) Figure 1.

The taxonomy of the theory types in information systems by Gregor (2006) was introduced earlier in this thesis in section 2.3.2 (Observation, theory and phenomena). The fifth type of theory in the taxonomy was the Theory for Design and Action. Gregor and Jones (2007, 325-329) have further elaborated upon this theory type by suggesting that there are eight components which design theories in information systems contain. Six of these components are core components present in all the theories, and the remaining two are additional and may or may not be present. The components are as follows:

1. Purpose and scope: the set of objectives and boundaries, which specifies the type of systems and circumstances to which the theory applies
2. Constructs: the building blocks or the phenomena of interest in the theory
3. Principle of form and function: the general principles that define the design product or method (structure, organisation, functioning)
4. Artefact mutability: reflections on the way artefacts emerge and evolve in socio-economic contexts and practices
5. Testable propositions: hypotheses about the artefact to be constructed that can be proven true or false (algorithmic propositions), or functional or dysfunctional (heuristic propositions)
6. Justificatory knowledge: explanatory knowledge about goals, shape, processes and materials; causal and/or teleological explanations of why the artefact works
7. Principles of implementation: the means of bringing the design into material existence
8. Expository instantiation: The material artefact produced by the implementation of the design theory

Although the anatomy of the design theory presented above has been developed for design theories in information systems, it appears to be general enough to be also adopted in engineering design research. Comparing the components with the typologies comprised of engineering knowledge (see Table 4 on page 49) suggests that engineering design theory contains similar knowledge elements of know-that, know-how, know-what and know-why. These connections are illustrated in Table 6.

Table 6. Knowledge types of engineering present in the components of design theory

Component of design theory	Related knowledge type	Example of a related question
Purpose and scope	Know-why, know-how	What is the design theory intended for? Where and how can it be applied?
Constructs	Know-that	What are the elements or phenomena present in the design theory?
Principle of form and function	Know-what	What is the very essence of the design? What makes the design work?
Artefact mutability	Know-why	How can and will the design be used in the future?
Testable propositions	Know-that, know-how	What elements of the design theory can be verified and how?
Justificatory knowledge	Know-that	What explains why the design works or should work?
Principles of implementation	Know-how	How can the design theory be instantiated?
Expository instantiation	(Material artefact)	Could the design be implemented in practice?

3.3. Knowledge creation in engineering and engineering science

Whether some kind of distinction can be drawn between engineering and engineering science as proposed in Figure 5 is far from clear. The respective terms are also used in various manners. Sometimes the term *engineering* refers to all kinds of knowledge and knowledge creation within the area (see e.g. Simon 1996); sometimes the term *engineering science* is similarly used (see e.g. Hendricks et al. 2000). Some identify engineering with processes of engineering design and engineering science with the processes of scientific research (see e.g. Kroes 2009a). For others, the difference is defined institutionally; that is, engineering science is the engineering-related knowledge creation done at technical universities and engineering the knowledge creation done at companies. However, as presented earlier, there have also been attempts to differentiate between the two terms conceptually.

Thus, trying to separate the processes and methods of knowledge creation in engineering and engineering science may also be arbitrary and even confusing. Nevertheless, if the idea exists of engineering and engineering science being at least partly different activities, it seems reasonable to try to examine where the differences lie with respect to knowledge creation.

3.3.1. The purpose of engineering and engineering science

Perhaps the most quoted description about the differences between science and engineering is Simon’s (1996) statement that science states how things are and engineering states how things ought to be: “The engineer, and more generally the designer, is concerned with how things ought to be – how they ought to be in order to attain goals, and to function.” (Simon 1996, 4) Clearly, there is some overlap, for in order to be able to steer matters towards more a desirable direction, one first needs to know how things are in actuality.

Hendricks et al. (2000) divide puzzle-solving in engineering into two types with different aims. The first aim of engineering is to understand a specific problem. The second aim is to develop a method to solve a problem. This second aim also includes the assessment of the method developed in relation to suitable criteria such as usability, optimisation and stability. Järvinen (2004, 8) has taken this view to a more general level and suggests that understanding, construction, re-engineering and evaluation of artefacts or systems of artefacts are possible purposes of all scientific inquiry. Kroes (2009a), on the other hand, perceives engineering and engineering science as having different objectives: engineering is about inventing something novel, and engineering science is about discovering existing things. Thus, engineering is about creating a construction and engineering science is about determining the feasibility of the construction in a scientific manner.

The quest for practically feasible solutions rather than for the ultimate truth is reflected in many ways in the knowledge-creation processes of engineering. Following Kuhn’s (1996, 181-187) notion of paradigm as the constellation of group commitment, which he also calls the “disciplinary matrix,” Hendricks et al. (2000) defined technical matrices for pure science, applied science and engineering science to bring to light the philosophical differences between the three types of disciplines. They used the term *technical matrix* instead of *disciplinary matrix*, as Kuhn never intended the conception to be applicable outside of pure sciences (ibid, 283). The central ideas of technical matrices in pure science and engineering science are presented in Table 7.

Hendricks et al. (2000) suggest that theoretical truth is not a Kuhnean value of engineers. This is illustrated in the technical matrix, particularly in the theory structure and use of methods. Engineers tend to have a highly eclectic use of basic theory depending on the particulars of the problem, and the field is poly-paradigmatic in nature, as several schools can co-exist simultaneously without having any strong incommensurability among their technical matrices. Also, the use of methods reflects pragmatic values over truth, as engineers are in need of design data rather than assessments of theory or hypotheses, and can even accept the use of “truth-wise” unreliable methods as long as the data obtained is reliable enough for design purposes.

Houkes (2009) has criticised the arguments like the one above for relying on “truth vs. usefulness” (TU) intuition, which is not justified or tested but taken for granted as a basis of further argumentation. His critique, however, is targeted mainly at the assumption of truth as the objective of science, and not at the assumption of usefulness as the objective of technology and engineering science. Similar views are expressed by the New Experimentalists, who suggest that in contemporary natural sciences, where technological instrumentation is necessary for the study of many phenomena, the need for theoretical understanding of a given phenomenon is not merely for the sake of theory, but also for the sake of understanding how the phenomenon is technologically produced. This makes the creation of phenomena by means of technological instruments also an aim in natural science. (Boon 2013, 82.)

Table 7. Technical matrices of pure science and engineering science, adopted from Hendricks et al. (2000)

	Pure science	**Engineering science**
Objects of study	Objects isolated from the environment and conceptually idealised for study Causal mechanisms	Physical (real) entities and artefacts in environments created by man Intentionally determined
Epistemic and ontological assumptions	These assumptions are essential, as metaphysical debates are debates about the truth, and inquiry aims at finding the truth	Adopted from pure science if needed Only of little interest as the assumptions have no pragmatic consequences
Theory structure	Hierarchical structure of nomological systems Mainly mono-paradigmatic	Theory adopted to problems Polyparadigmatic Ecclectical use of theory
Methods	Derived from theory	Methods are more fundamental than theory Methods used to provide useful design data rather than to assess a hypothesis
Values	Explicit justification Truth is important	Implicit justification Efficiency and practical usefulness Pragmatic concept of truth
Function of exemplars	Building research competence	

Engineering problems are, however, sometimes approached from the technical matrix of natural sciences. Hukka et al. (2007) have demonstrated several problems arising from the application of positivistic research philosophy in water resource management research. They note three particular issues: 1) the positivistic approach typical to natural sciences often deals with an isolated topic without wider connections to the problem environment (an isolated and idealised object of study), 2) the selected methodology and approach are taken for granted (methods are derived from the theory rather than from the problem), and 3) no critical evaluation of the performed research is presented (assuming that the correct method ensures the truth and no evaluation against other criteria is needed). In their opinion, a greater variety of theories, approaches, methods and strategies is needed to ensure a better social impact, validity and relevance of the water research.

Although practical usefulness seems to be strongly connected to technological knowledge, Jørgensen (2007, 233-234) has noted a change within this realm. He suggests that the 19th century idea of engineers as the heroic constructors of modern society started to transform in the beginning of the 20th century into an image of engineers as servants of industry. Alongside this has come the change of identity from engineers as creators and designers to engineers as analysts and scientists. This includes the idea of engineers working more with well-defined technical problems and less with undefined and non-standardised social and technical processes. (Ibid.) This shift could be interpreted as the concept of practical usefulness being reduced mostly to economical issues, as opposed to including also environmental and societal issues. It could also imply a transformation of focus from design to research.

3.3.2. Methods and methodology in engineering

Eekels (2000 & 2001) uses the term *methodics* when referring to the whole body of engineering design methods and systems of methods. According to him, methodics do not belong to the category of scientific knowledge, but they can be an object of scientific inquiry. Eekels calls the descriptive and prescriptive study of engineering methodics “engineering science methodology.”

Methods used in engineering encompass many kinds of activities. Vincenti (1990, 229-234) identifies seven different knowledge-creating activities:

1. Transfer from science: the use of scientific theories as theoretical tools and in the production of quantitative design data. The transfer from theoretical science often involves reformulation or adaptation to make the knowledge useful for engineering.
2. Invention: a source of totally novel ideas such as operational principles or normal configurations. An elusive, creative enterprise.
3. Theoretical (mathematical) engineering research: mathematical modelling of phenomena to produce parametric design data or computer simulations to provide design procedures.
4. Experimental engineering research: experimental testing, which may or may not be based on theoretical physical models. Much of it is similar to scientific empirical research, but engineering also employs certain methods, such as experimental parameter variation or destructive testing, in its own characteristic ways.
5. Design practice: day-to-day design practice often comes across with new problems, for which ad hoc methods are devised. These can later be developed further by other means of knowledge creation.
6. Production: some problems of engineering designs are not revealed until the design is in production. Especially contributes to the quantitative data needed in engineering design.
7. Direct trial: Testing of readymade devices either by proof tests or in customers’ real use in everyday operations. Feedback may result in all types of engineering knowledge.

The activities mentioned above relate more to the sources of knowledge than to mechanisms of knowledge creation. As a general mechanism or engineering method for knowledge-creation, Vincenti (1990) proposes the variation-selection model for the growth of knowledge.

The variation-selection model consists of mechanisms for introducing variation, processes for selecting the most promising variations, and mechanisms for preserving and propagating the selected variations. The mechanisms for producing variation entail, in Vincenti's view, at least three hidden, mental activities: 1) the search for past experience with similar situations, 2) the incorporation of novel features called for by new circumstances of the past experience, and 3) the mental winnowing of the conceived variations to select the ones most likely to work. The activities do not proceed sequentially, but rather concurrently and interactively. The processes of selection in technology are increasingly occurring through vicarious rather than direct trials. These vicarious procedures include the use of partial experiments, complete simulations, or analytical tests instead of physical trials. However, in the end, all designs and design knowledge must be borne out in operation. Thus, also direct trials such as proof tests and customer experience with the complete product can also be viewed as a part of the selection process. The propagation of selected variations then takes the form of journals, textbooks, handbooks, curricula, design traditions and other contemporary methods by means of which knowledge is transferred.

3.3.3. Methods and methodology in engineering science

The research approach applied in scientific inquiry depends on the purpose of the study. Järvinen & Järvinen's taxonomy of research methods (see Järvinen 2004, 9-14) first makes a separation between the approaches studying reality and the mathematical approaches. The approaches studying reality are further subdivided into research studying what reality is (how things are) and research studying innovations (how things ought to be). The entire taxonomy is presented in Figure 8.

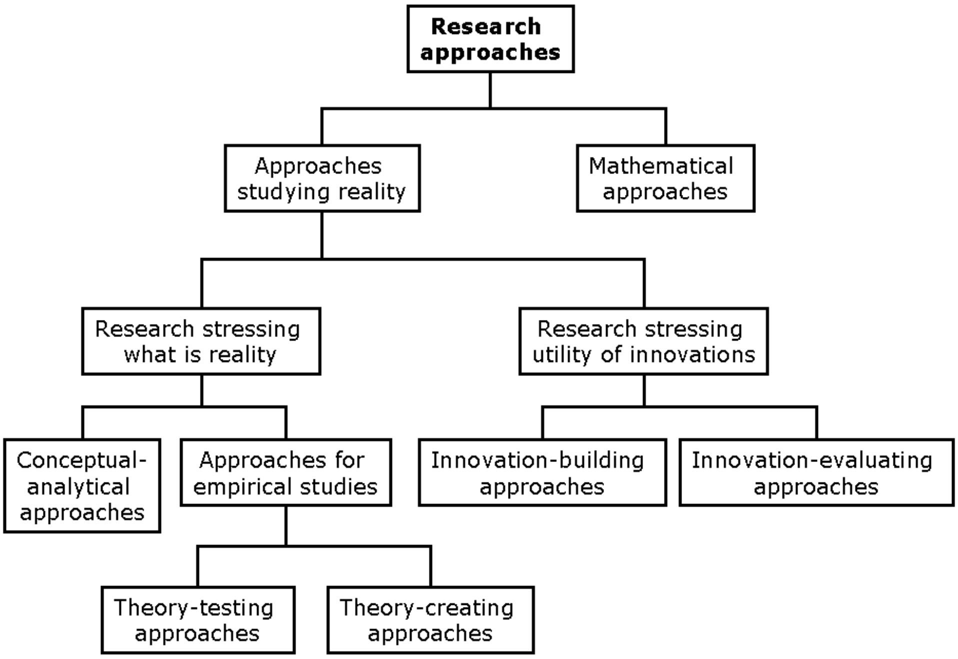

Figure 8. Järvinen & Järvinen's taxonomy of research methods (Järvinen 2004, Figure 1.3)

The constructive approach is one of the most commonly used research approaches in Finnish engineering science research. The theory of the constructive approach has been discussed mainly in the framework of management accounting research (see e.g. Kasanen, Lukka & Siitonen 1993). Other widely used research approaches in accounting research are the nomothetical approach, conceptual approach, decision-oriented approach and action-oriented approach (see e.g. Olkkonen 1994). These five research approaches differ from each other with respect to their descriptive versus normative and theoretical versus empirical nature, as illustrated in Figure 9.

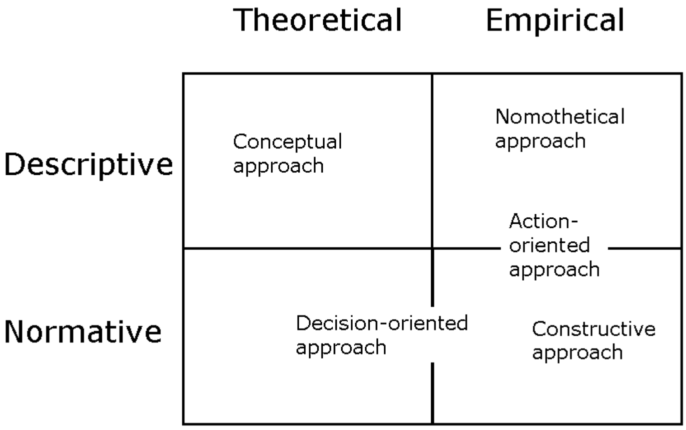

Figure 9. The research approaches in accounting research (adopted from Kasanen et al. 1993, Figure 4)

The nomothetical approach aims at finding causalities through empirical testing in a somewhat similar manner as in the natural sciences. In the conceptual approach, the objective is to describe phenomena by creating new concepts or sets of concepts mainly through theoretical reasoning. Even when created to serve practical purposes, both laws resulting from nomothetical research and the conceptualisations resulting from conceptual research are descriptive in nature, as the knowledge they contain is about the present state of the world. Decision-oriented research aims at creating mainly mathematical models to be used in decision-making. Thus, it can be classified as theoretical. Action-oriented research aims at understanding the problem often through teleological models rather than causal explanations. Although action-oriented research is not always intended to use the situation or reality, it can include an active participation in a change process. In these cases, both action-oriented and decision-oriented research can be perceived as being normative, with an intention to change the world.

The constructive approach extends the idea of the decision-oriented approach from mathematical constructs to other constructs, and from the support of decision-making to the support of any appropriate action. Kasanen et al. (1993, 245) describe constructive research as “managerial problem solving through the construction of models, diagrams, plans, organizations, etc.” Nevertheless, all problem-solving activities do not count as constructive research, as the problem and its solution must be tied to the accumulated theoretical knowledge and novelty, and the actual functioning of the construction has to be demonstrated as well. In accordance with this, Kasanen et al. propose the following six-point scheme for the research process in constructive research:

1. Finding a practically relevant problem which also has research potential
2. Obtaining a general and comprehensive understanding of the topic
3. Constructing a solution idea
4. Demonstrating that the solution works
5. Showing the theoretical connections and the research contribution of the solution
6. Examining the scope of applicability of the solution

However, drawing the line between constructive research and scientific problem-solving is challenging. (Ibid.)

Constructive research typically applies the case method, but it does not incorporate strict methodological rules. There are several tools and methods suggested for the demonstration and evaluation part of the research in the area of managerial constructions, such as the weak market test, semi-strong market test and strong market test, but the research framework contains no general guidelines for either the construction or the evaluation part of the research.

Gremmen (2013, 76) calls “practical sciences” those academic disciplines that provide engineers with the knowledge needed for production and use of material objects. He points out that the answer to the question of how to manufacture an artefact is not identical to the act of manufacturing. The practical sciences aim *for* "prognosis of the behavior of a projected functional object, prognosis of the results of the projected procedure, determination of the structure and composition of a functional object necessary for a certain intended behavior, and determination of the procedures one should follow in order to achieve an intended effect" (ibid).

In Järvinen & Järvinen’s taxonomy, the nomothetical and conceptual research would be classified as research stressing reality; and the decision-oriented and constructive research as research stressing innovation. Action-oriented research could be either, depending on its objectives and execution. The aims of Gremmen's practical sciences suggest that the methods stress the utility of innovations through both building and evaluating innovations.

Simulation, and particularly computer simulation, is also widely applied in modern engineering science. Simon (1996, 13-17) suggests that there are two alternative ways in which a simulation can provide new knowledge: 1) It provides an analysis of a complex situation where all the systems’ components with their fundamental laws of behaviour are known, but the prediction of how an assemblage of such component will behave is difficult to make; or 2) It provides an analysis of a complex situation where all the components are not known, but the behaviour of the system can be approximated by building a simplified, abstracted characterisation.

In the first case, the simulation entails all the required premises and uses the calculation power of the computer to come up with a prediction or explanation of the situation that otherwise would be out of the researcher’s reach. In the second case, a simplified model of a complex system is synthesised based on the assumption that to simulate the behaviour of the system, the entire internal structure of the system does not have to be known. Instead, only a part of the internal structure will be crucial for mimicking the phenomena, thus allowing for the abstraction of the system. The resemblance in behaviour of the original system and the simplified abstraction is particularly feasible if the interesting aspects arise from the organisation of the parts instead of from the properties of the individual components. (Ibid.)

In the first case, the computer is used purely as a tool for calculations with the observations made and knowledge collected from the original system. In the second case, it can be argued that the system or phenomena to be observed is no longer the original (physical) one, but rather a “virtual experiment” conducted in a computer. According to Krebs (2007), computer simulations contain two levels of abstraction: first the conceptualising of real world phenomena into a mathematical model, and second the translation of the model and its dynamics into the realm of the virtual. He expresses concerns about the scientific rigour related to both of the abstraction processes. The sources of concern as regards the mathematical modelling are common to the whole of quantitative research, where the phenomena is to some degree abstracted, formalised, generalised and simplified. As for the second level of abstraction, Krebs states that the “challenge remains for the provision of suitable explanations of how the apparatus (computer) works, and more importantly how the model or simulation that is implemented on the computer relates to the real world. The explanations will need to be different, due to the inherent difficulties in demonstrating causal chains in a virtual world.” (Krebs 2007, 53) He also points out that a computer model needs to be testable in two ways, as the adequacy of both the model and its implementation must be tested to ensure the scientific rigour.

3.4. Norms and evaluation in engineering science

In their book *Tekniikan alan väitöskirjaopas* (*Dissertation Guide in Engineering Sciences*), Airila and Pekkanen (2002) name objectivity, progress, publicity, criticality, autonomy, truthlikeness and generality as the hallmarks of science. From these characteristics, they derive seven criteria for the evaluation of the scientific value of a dissertation work:

1. Novelty of knowledge
2. Publicity of knowledge
3. Truthlikeness of knowledge
4. Generality of knowledge
5. Publicity of research
6. Criticality of research
7. Autonomy of research

Four of the criteria refer to produced knowledge, and three to the knowledge-creation process. These follow the CUDOS norms well, with communalism contained in the categories of Publicity of knowledge and Publicity of research; disinterestedness in the category of Autonomy of research; originality in that of Novelty of knowledge; and scepticism in that of Criticality of research. The generality of knowledge refers to the informational value and lawlikeness of research results and implies that knowledge has a large explanatory or predictive power (Airila & Pekkanen 2002, 58). Thus, the norm of universalism, which includes objectivity in the sense that knowledge is separated from the person who created it, is represented in both truthlikeness and generality of knowledge.

As with the CUDOS norms, the suggested evaluation criteria is also challenged by the societal change reflected in Ziman’s PLACE norms. As is the case particularly in engineering, much of knowledge creation is now already proprietary, local, authoritarian, commissioned and expert. Technical universities in Finland have good connections with industry, and private funding plays a relatively big role in their total resources (Ala-Vähälä 2013, 12-13). This leads to the question of the relevance of PLACE norms also in engineering science. The connection among the suggested quality criteria, the CUDOS norms of science and the quality questions discussed in section 2.5 is illustrated in Figure 10.

In design science, the epistemic utilities of science, truth and information, are accompanied by a demand for relevance (Niiniluoto 1985). It has also been suggested that the theoretical truth is not a Kuhnean value in engineering science, or is at least secondary to practical usability (Hendricks et al. 2000). Meijers and de Vries (2013, 73) state that the truth as the sole criteria for knowledge is challenged by a particular epistemological interest related to practical reasoning through a "use plan" of an artefact. This knowledge of functions of an artefact also embeds a normative component in statements that otherwise seem neutral; an artefact called something specific is expected to fulfil the use plan of that particular artefact. For example, an item called "hammer" is expected to function as a hammer. This makes the use of related criteria, such as prudence or efficiency, criteria as well for the knowledge of statements of this sort.

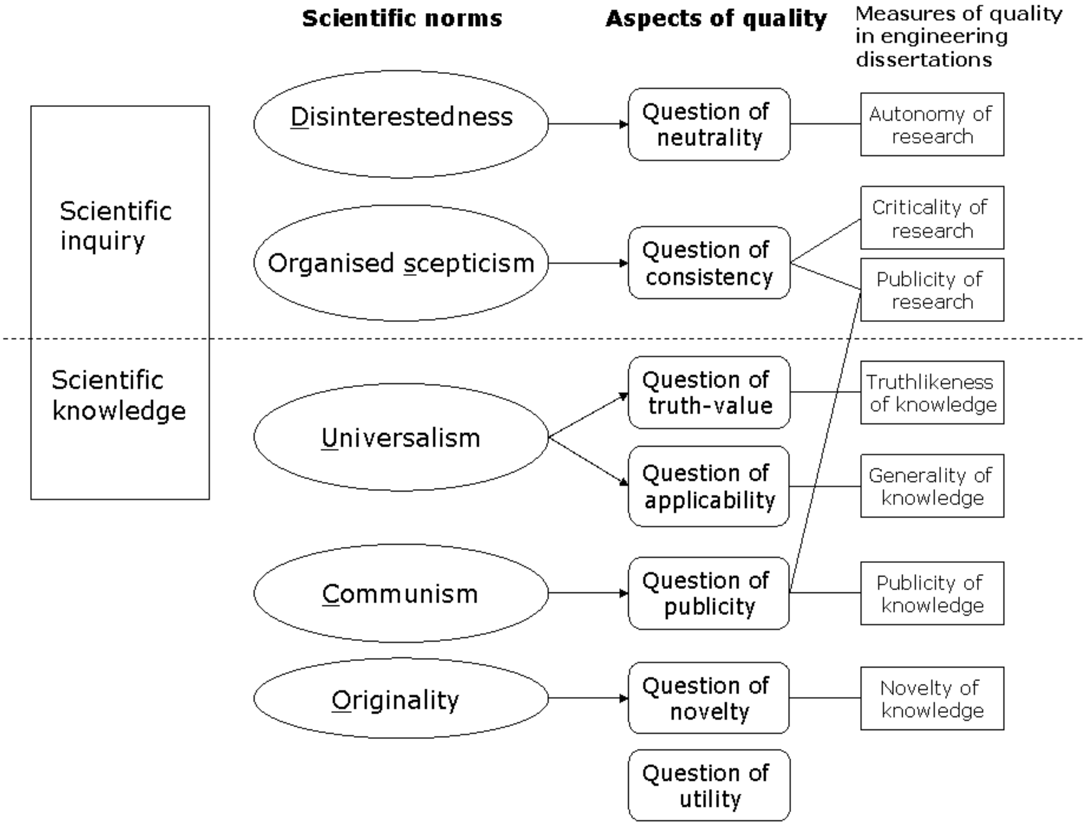

Figure 10.CUDOS norms and questions of quality in engineering science

The presence of truth-related criteria and absence of practical-relevance-related criteria raise the question of the applicability and sufficiency of criteria proposed by Airila and Pekkanen for engineering science. If engineering science is understood merely as engineering or technological research, it can be seen as being guided by the values and norms of theoretical rationality, and the results then appear to be fundamentally independent of the social context (Kroes 2009b). If, however, engineering science is thought also to compass activities of engineering design, the situation changes. Engineering design is guided by the demand of practical rationality, and the kind of actions and ends that are always embedded in value-laden social contexts with constraints of their own (ibid). The lack of clear criteria for evaluating the outcome of the design processes can also lead to a situation where the instrumental rationality of the design activity is emphasised at the expense of creativity (Kroes 2013, 115-116). Focusing only on aspects such as efficacy or efficiency of the design outcome neglects the evaluation of the design process, where decisions about the various options are made. Yet, creativity and rationality are complementary elements, and both are necessary to effective engineering design.

3.5. Summary

This chapter has discussed the philosophical aspects of engineering and engineering science and has attempted to differentiate between the two. The approach began with a brief look into the historical development of the debate around the issue. Before the arena of engineering science was entered, the relationship between technology and science was viewed from different angles. Engineering science was noted to be a concept that can be understood in many ways. Some use the term to denote only a research type of scientific inquiry done in the engineering topics, and place all the design science kind of activities under the umbrella of engineering design. In this approach, engineering science and engineering design are seen as different, mutually exclusive processes, with diverse types of problems addressed. Another possibility is to understand the term *engineering science* broadly. In the broad definition, inquiry into engineering science may include both research and design type of objectives and processes. According to this approach, engineering science and engineering design are overlapping rather than exclusive activities. This study uses the latter, broad approach to engineering science.

Knowledge in technology and engineering was discussed with respect to different levels and types of knowledge; and the possible differences between technological, engineering and engineering science knowledge. Some typologies of engineering knowledge were presented in more detail, and interrelations between them were suggested. The stratification of engineering design science by Eekels (2000&2001) was presented as one of the attempts made to demarcate between engineering and engineering science. The suitability of Gregor's (2006) taxonomy of theory types in information systems for engineering was contemplated as well.

Knowledge creation in engineering and engineering science was first addressed in contrast to knowledge creation in pure science, and then the technical matrix of engineering science as proposed by Hendricks et al. (2000) was introduced. Methods and methodology in engineering were discussed mainly in reference to Vincenti's (1990) work. Methods and methodology in engineering science were approached with the help of the constructive approach used in management accounting research, and the role of simulation in modern engineering science was touched upon as well.

Lastly, the discussion about norms and quality which began in Chapter Two was continued form an engineering science perspective. The theoretical truth has been suggested to be of secondary value when compared to practical usability in engineering science (Hendricks et al. 2000). Moreover, truth as the only criteria for knowledge in engineering has been challenged by a particular epistemological interest related to practical reasoning (Meijers and de Vries 2013, 73). Hence, the applicability and sufficiency of the traditional criteria for quality of science was questioned.

The next chapter will explore doctoral education in Finnish engineering science. Its aim is to find out whether the issues presented in this chapter and the previous chapter of this dissertation are present in doctoral training.

4. Doctoral education in Finnish engineering science

> *Objectives of scientific and artistic postgraduate education*
> *1. The aim of postgraduate education is that the student:*
> *(1) becomes well-versed in his/her own field of research and its social significance and gains knowledge and skills needed to apply scientific research methods independently and critically and to produce new scientific knowledge within his/her field of research;*
> *(2) becomes conversant with the development, basic problems and research methods of his/her own field of research; and*
> *(3) gains such knowledge of the general theory of science and of other disciplines relating to his/her own field of research as enables him/her to follow developments in them.*
> *(Government Decree on University Degrees 794/2004, Section 21)*

Postgraduate education is about training people in the art of scientific research. The educational process is affected by national, disciplinary and organisational cultures.

This chapter briefly outlines the Finnish system of postgraduate education, especially from the viewpoint of engineering. It also presents some earlier findings about the challenges in doctoral education. The noted challenges relate to certain philosophical questions and suggest that there are gaps in either the common understanding of these philosophical issues or the communication of them to doctoral students enrolled in Finnish engineering science. Added to the issues of Chapter Three is the construction of a framework for empirical study and the identification of a research gap.

4.1. Doctoral education in Finland

The Finnish higher education sector consists of two kinds of institutions: universities and polytechnics. Polytechnics offer more professionally oriented undergraduate and graduate degrees. The degree education at universities is based on research and organised in the form of Bachelor’s, Master’s, licentiate and doctoral degrees. There are currently sixteen universities in Finland, of which fourteen are corporations under public law, and two are organised as foundations governed by the Foundations Act. (Universities Act.)

To complete his/her doctoral degree, a doctoral candidate needs to complete the studies required for postgraduate education, demonstrate the ability for independent critical thought and prepare a publicly defended doctoral dissertation (Government Decree on University Degrees, Section 22). The studies required for the degree vary in both extent and content, depending on the discipline and university. Typically, the requirements are between 40 to 60 study credits, with one study credit equalling 27 hours of student work. For a full-time student, the completion of a doctorate degree should take approximately four years.

A Master's degree from either a university or polytechnic grants eligibility for doctoral studies, but the university may require the student to complete some supplementary studies in order to acquire the knowledge and skills needed for the studies. (Universities Act, Section 37) Typically, a doctoral student holds a Master's degree from a university, as the master's degree has thus far been available in polytechnics for only few years.

The threshold for entering postgraduate studies has typically been low in Finnish universities, and the number of doctoral students is much larger than the number of doctoral degrees awarded yearly (Dill et al. 2008, 27). The number of doctoral students and of doctoral degrees awarded in 2012 in different disciplines is displayed in Table 8.

Table 8. Postgraduate students and awarded doctoral degrees in different disciplines in Finnish universities in 2012 (Vipunen 2013)

	Postgraduate students		**Awarded doctoral degrees**		
Field of education	**Number of students**	**of which women**	**Number of degrees**	**of which for women**	**Completed degrees per student**
Engineering	**4417**	**29 %**	**336**	**27 %**	**8 %**
Natural sciences	2825	46 %	323	45 %	11 %
The Humanities	2293	67 %	157	65 %	7 %
Social Sciences	1982	59 %	129	56 %	7 %
Medicine	1675	67 %	268	62 %	16 %
Economics	1254	50 %	98	44 %	8 %
Education	1185	76 %	84	79 %	7 %
Health Sciences	507	89 %	50	90 %	10 %
Agriculture and Forestry	500	58 %	41	59 %	8 %
Law	387	46 %	24	46 %	6 %
Theology	348	48 %	19	47 %	5 %
Psychology	305	73 %	28	68 %	9 %
Art and Design	289	61 %	19	68 %	7 %
Pharmacy	166	68 %	27	56 %	16 %
Music	126	52 %	10	50 %	8 %
Veterinary Medicine	122	78 %	11	64 %	9 %
Dentistry	95	66 %	12	75 %	13 %
Sport Sciences	67	49 %	9	22 %	13 %
Theatre and Dance	48	60 %	2	0 %	4 %
Fine Arts	33	58 %	2	0 %	6 %
Sum total	*18624*	*53 %*	*1 649*	*51 %*	*9 %*

Many doctoral candidates wish to study on a part-time basis and remain employed by organisations other than the university. Martinsuo (2007, 36) suspects this is due to their career aspirations, lack of proper research funding or fear of temporary employment. These students participate in doctoral education to strengthen their expertise alongside their actual employment and tend to have no intention of finishing their doctorate in four years (ibid). In fact, it may be that some students enrolled in doctoral studies have no intention of obtaining a doctoral degree at all but just wish to benefit from the free university courses and study modules as a form of continuing education.

4.1.1. Recent research into Finnish doctoral education

Välimaa (2012) identifies the five most important topics in Finnish higher education research to be 1) student-focused research, 2) follow-up studies of educational reforms, 3) pedagogical research, 4) research concerning polytechnics, and 5) studies on the management and administration of higher education. As polytechnics have no doctoral education, and as educational reforms, administration and management usually relate to all levels of university education, the remaining topics of students and pedagogy are expected also to be generally studied issues of doctoral education. This appears to be the case.

The sociological research aiming at understanding the process of doctoral education as part of a doctoral student’s life course is for instance well illustrated in Maunula (2014) and Peura (2008). Other kinds of studies, such as Lahenius (2013) and Stubb (2012), concentrate more on student experiences and conceptions of the pedagogical practices in doctoral education and supervision. Yet, common to all of these studies is the focus on student experience and the perception of the dissertation work as personal learning and development rather than as a scientific research process.

Pyhältö, Nummenmaa, Soini, Stubb and Lonka (2012) presented their results from a national research project on PhD Education in Finland. The project aimed at understanding 1) the central regulators and preconditions for a successful PhD process, 2) academic supervision, and 3) the dynamics of research groups as learning environments for academic expertise. The data was collected from students, supervisors and scholarly communities (such as research groups or seminar participants). The results suggest that a high quality doctoral education cannot be defined in terms of fixed attributes or of a certain set of practices carried out in a research group; the focus should be on student participation in networks and groups and on interaction with other experts. Also, this research views the dissertation work from the standpoint of the development process.

Concerning doctoral education in engineering, previous academic research mainly comes from the field of industrial engineering and management. Lahenius and Martinsuo (2011) have identified three different types of study processes as well as doctoral students' experience and use of study plans (Lahenius & Martinsuo 2010).

Martinsuo and Turkulainen (2011) studied the effect of personal commitment and support for the progression of doctoral studies. These studies represent sociological-pedagogical research into doctoral education, too.

The learning, teaching, supervision and socialisation processes of Finnish doctoral education have thus been studied quite extensively. Less attention, however, seems to have been paid to the content of the learning; i.e., scientific thinking and research skills, at least in the area of engineering science.

4.1.2. Evaluations concerning Finnish doctoral education

In addition to being evaluated through the academic research, Finnish doctoral education has been thoroughly evaluated administratively over the past decade. Evaluations have been conducted in relation to both international and national demands and challenges from the viewpoints of society as well as those of the individual doctoral student. In September 2002, the Finnish Ministry of Education formed a subcommittee to investigate the need for and employment of doctoral graduates in different disciplines and to evaluate the operation and development needs of graduate schools. The committee finished its work in autumn of 2005, and the results were published at the beginning of the year 2006. (Tohtorikoulutuksen kehittäminen 2006.) In December 2004, the Finnish Higher Education Evaluation Council (FINHEEC) launched an international evaluation concerning the whole field of doctoral education. The international evaluation panel performed its work based on documents and site visits. The panel's report includes several recommendations and ideas for development directed partly at national level actors and partly at universities (Dill et al. 2006).

Both working groups arrived at rather similar conclusions and recommendations. On the national level, the development of financing and of quality assurance in the graduate school system was advised. Also, better collection and use of statistical data was desirable both nationally and locally at the university level. Universities were encouraged to recruit more international doctoral students and visiting lecturers and also to promote the mobility of Finnish students. In the area of quality assurance, universities were asked for clearer policies regarding the recruitment of doctoral students, the supervision of doctoral studies and dissertations, the content of doctoral education and the evaluation of all of the above. (Tohtorikoulutuksen kehittäminen 2006, Dill et al. 2006.)

The experiences and opinions of doctoral students pertaining to the doctoral education they had received were examined in a survey study executed in spring 2005. The study was commissioned by the Ministry of Education. The survey targeted all those registered as doctoral students in Finnish universities, both inside and outside of graduate schools. The survey was responded to by nearly four thousand students, which allowed the researchers to also analyse the disciplinary differences. (Hiltunen & Pasanen 2006.)

The survey revealed that according to doctoral student opinion, the two issues needing the most development are the introduction to doctoral studies and supervision during doctoral studies. Only about half of the students had received as much supervision as they had hoped for. Students were generally satisfied with the development of their research skills but wished for more improvement in their general employability skills: only three students out of ten felt that their doctoral education had trained them enough for a career outside of academia. (Ibid.)

4.2. Doctoral education in the engineering sciences

Doctoral education in the engineering sciences follows the general trends in doctoral education in many respects. The number of doctoral students is large compared to the number of doctoral graduates. The 8% yield is slightly lower than the average in all doctoral education (9%). One remarkable difference from other fields of education is the small number of women in the number of both doctoral students and doctoral graduates—all in all, women are already slightly overrepresented in doctoral education, but in the engineering sciences, the proportion of women is about a quarter of the candidates and graduates.

There are seven Finnish universities providing doctoral education in engineering sciences. The extent of engineering education in different Finnish universities varies greatly, ranging from some universities providing education in only one or two majors to some universities having several faculties of engineering sciences. Table 9 presents the number of graduate doctors in engineering in the years 2010-2012 at different universities.

Table 9. Number of doctoral degrees awarded in engineering sciences during 2010-2012 in different Finnish Universities (Vipunen 2013)

	2010		**2011**		**2012**	
University	**Degrees**	**of which for women**	**Degrees**	**of which for women**	**Degrees**	**of which for women**
Aalto University	153	25 %	136	28 %	155	21 %
Tampere University of Technology	87	30 %	75	27 %	90	28 %
Lappeenranta University of Technology	34	21 %	37	32 %	36	31 %
University of Oulu	26	23 %	42	14 %	28	32 %
Åbo Akademi	11	36 %	14	50 %	18	67 %
University of Vaasa	4	0 %	3	0 %	2	0 %
University of Turku	3	33 %	4	0 %	7	0 %
Sum total	*318*	*26 %*	*311*	*27 %*	*336*	*27 %*

When the career structure of the young doctors (who graduated between 2004 and 2005) was surveyed, it was noted that 39% of all graduates had carried out their doctoral studies while being employed elsewhere. This is slightly above the average of all fields of education (35 %). The employment situation after graduation was better than in many other fields, with almost half of the graduates being employed by the private sector. (Haapakorpi 2008.)

4.2.1. Degree structure and requisites

The structure of a doctoral degree in engineering sciences depends on the university, but is still quite similar in all seven Finnish universities. Before 2012, the required studies were in total 60 study credits in all doctoral degrees in engineering. They were usually divided into modules of general studies, major and minor, although the terms used for these modules were a somewhat diverse in different places. However, this is the structure followed by the doctoral candidates whose dissertations form the primary data of this study.

During 2012, the degree structure was altered in almost all Finnish technical universities and faculties. At that point, the minimum extent of required studies became 40 credits, and the module of minor studies was excluded from most degrees. Some faculties, however, still maintained the requirement of 60 credits of studies. The extent of the different modules and the description of the contents of general studies in 2011 and currently are presented in Table 10.

In addition to his/her studies, a doctoral candidate is required to prepare a doctoral dissertation and defend it in public. A dissertation can be a monograph or a compilation of articles. An article-based doctoral dissertation is comprised of a summary section and of separate, mostly refereed journal articles that have been accepted for publication in either journals or conference proceedings. The required number of articles depends on both the field of engineering and the traditions of the university. The articles may be joint publications, provided that the doctoral candidate's independent contribution can be identified.

All doctoral dissertations undergo a formal public examination. This ensures that the dissertation meets the required academic standards. A candidate is appointed one or two opponents, who must hold a doctoral degree. The public examination offers the opponents and other interested parties the opportunity to familiarise themselves with the content of the dissertation and discuss this with the doctoral candidate. Those present at the public examination may announce that they wish to submit comments regarding the dissertation, and they deliver the written comments to the organ responsible for evaluating the dissertation. Also, the opponents provide a written statement concerning the dissertation for evaluation purposes. The organ responsible for the evaluation, usually the faculty council, decides upon the acceptance or rejection of the dissertation and awards the grade.

Table 10. The structures of doctoral degrees in the engineering sciences at different Finnish universities in 2011 and currently; amounts in ECTS

	In 2011					**Currently (changes made mostly during 2012)**			
University	**ECTS total**	**General studies**	**Major**	**Minor**	**Content of general studies**	**ECTS total**	**General studies**	**Major**	**Content of general studies**
Aalto University [1]	60	5-15	30-40	10-20	Studies addressing the preparation for scientific work, and the application and dissemination of scientific knowledge	40	5-20	20-35	Research methodology and ethics, history and philosophy of science, academic writing; part of the module can consist of learning about university practices
Tampere University of Technology [2]	60	Min. 5	Min. 35	Option-al		40	Min. 5	Min. 25	Strongly recommended introductory course
Lappeenranta University of Technology [3]	60		35-40	20-25		40	10-15	25-30	In the Faculty of Technology, general studies must include a course on the academic writing of publishing. In the Faculty of Industrial management, the whole degree must include 5-20 credits of methodological studies.
University of Oulu [4]	60	5-8	35-45	10-20	General studies relating to scientific activity or history of science	40	4-8	32-36	Compulsory introductory course, course on ethics and research plan seminar; can include some teaching
Åbo Akademi [5]	60		40	20	The major includes advanced special studies in one's subject and/or conduction of research.	40 chem. 60 comp.	0-15 chem. 20 comp.	25-40 chem. 40 comp.	Studies helping with the research work, can include 5 cr of language studies (chem.) Degree can also include a minor instead of general studies (comp.)
University of Turku [6]	60	Approximately 10 credits of general studies recommended			Philosophy of science, research ethics, university pedagogy, scientific communication, language studies, project work, leadership or management studies	60	6-10 credits of general studies recommended		Philosophy of science, research ethics, university pedagogy, scientific communication, language studies, project work, leadership or management studies
University of Vaasa [7]	60	5-15	30-40	15-20	Studies supporting the conduction of research and production of general scientific capabilities; e.g. research methodology or the philosophy /history of science	40	5-10	30-35	General studies should support conduction of research and production of general scientific capabilities; can include some teaching or thesis supervision

1) Aalto University (2013) 2) Tampere University of Technology (2013) 3) Lappeenranta University of Technology (2013) 4) University of Oulu (2013) 5) Åbo Akademi (2013a&b) 6) University of Turku (2013) 7) University of Vaasa (2013)

4.2.2. Support and supervision

Hiltunen and Pasanen’s (2006) survey revealed that doctoral students enrolled in engineering sciences were more satisfied with their funding than were doctoral students enrolled in other disciplines. Three-quarters of the engineering students worked alone as opposed to in research groups; 91% wrote their dissertation in English, and 64% were working on a compilation-format style dissertation. When the experiences of doctoral students in engineering were compared to those of students from other disciplines (natural sciences, medicine and health sciences, social sciences, and humanities), statistical differences emerged, especially in the areas of supervision and critical thinking.

Engineering students assessed their development in research skills as weaker than did the students from the humanities or social sciences. The research skills consisted of knowledge about methodology, knowledge about theories, the ability to conduct research independently, written and oral communication skills, a systematic approach, and the development of different viewpoints. The same weakness occurred with respect to the development of values. This included broadening of conventional wisdom, understanding of cultural diversity, reflection of values, development of society, and understanding of gender differences. Both differences were statistically significant. (Ibid, pictures 27 and 31.)

Compared to humanistic students, engineering students evaluated the functionality of supervision (availability of supervision, comfort with the supervisory situation, shortcomings in supervision, and the desire to change one’s supervisor) as being weaker. This difference was also statistically significant. Regarding the content of the supervision, the engineering students’ experiences were significantly worse than the experiences of students in all the other disciplines. The content of the supervision variable consisted of such matters as supervisors’ interestedness, methodological supervision, theoretical supervision, reception of constructive criticism, discussion of future plans, and general possibilities for discussion. In particular, the supervisor’s interestedness, methodological and theoretical supervision, and constructive criticism were perceived to be weak in the engineering sciences. (Ibid, 44-45, picture 23.)

Lahenius and Martinsuo (2011) identified three different groups of study processes among the doctoral students of industrial engineering and management. The groups clearly differed in their experiences of support and supervision during their studies but also in their readiness to seek out support and supervision. The part-time students especially had difficulties with starting to think in a scientific way. For the students working full-time in a given scientific community, this way of thinking was not equally difficult. This suggests that the community plays a role in supporting the development of scientific thinking and that rather than being explicitly taught or transferred through supervision, thinking skills result from indoctrination into the community culture.

4.2.3. Role of the philosophy of science in doctoral education

Peltonen's (2005) study about the role of the philosophy of science in the course of both doctoral studies and the writing of a dissertation at Helsinki University of Technology revealed that the connection between the philosophy of science and one’s own research depended on the department. The results are presented in Table 11. Different attitudes came across in student interviews and were further enforced by the interviews of the supervisors. Many interviewees doubted the actual need for philosophy in research. Sometimes the relevance of the philosophy of science to the research was recognised in humanistic or social science research, but not in the natural or engineering sciences. (Ibid, 31.)

Table 11. The view of the connection between the philosophy of science and research in the engineering sciences in different departments (Peltonen 2005, Table 3)

Department	**The connection between the philosophy of science and one’s own research or one’s department’s research**
Physics	Philosophical questions are related to physics, such as the problems with certain methods and interpretation of theories; yet an acquaintance with the philosophy of science is perceived more as a motivation factor than as a concrete and useful tool.
Mechanical engineering	Philosophical questions do not have apparent relevance in the field’s research. Supervisor mentioned that the choice of research topics is influenced by industrial interests (see also department of electrical engineering).
Electrical engineering	The instrumentalist view of the objectives of science and choice of research topics is typical to the field. Research is often design science with the aim of developing a functioning solution to a real-life problem. Philosophical questions arising in the course of the actual research process were not mentioned.
Industrial management	Philosophy has a concrete role in the making and defending of one’s research; e.g., in making and justifying methodological choices and realising and explicating the basis of research.

The study also identified three challenging areas in doctoral studies: 1) choosing and using research methods, 2) publishing, and 3) internalising the mode of scientific thinking. These topics were present in both students’ and supervisors’ statements.

Opinions about methodology were somewhat dualistic in nature. Most of the interviewees regarded methodology as a non-problematic area of research. It seems that methodology is not necessarily perceived as being separate from the substance or as an independent skill in research. Some methods were also presented as superior to others, and their technical use was emphasised without their epistemological limitations being discussed. Thus, philosophical problems related to methodology remain alien to many students. Some interviewees, however, brought up the challenges in justifying the methodological choices. It was also noted that students have difficulties understanding which methods best suit their research question and objectives. Sometimes the methods are chosen by looking at other students’ theses, as proper methodological supervision is not available. (Ibid, 33-34.)

The challenges in publishing relate to difficulties both in producing text (deficient language skills and lack of routine in writing) and in argumentation. Peltonen suggests that the aforementioned methodological optimism and trust in data may undermine the need for argumentation skills. Merely interesting observations are seldom enough to make for a good publication, but it is essential to be able to justify the basis, meaning and significance of the research. (Ibid, 37-39.) Explicating these to others is difficult if they are not clear to oneself.

Adopting a scientific way of thinking was also cited as a challenge during doctoral studies. It was mainly understood as the skill of asking questions, and was defined in three different ways. Firstly, it was perceived as being opposite to the engineering way of thinking: engineers are used to finding solutions to given problems, and then they move on to another project. Science, however, is not a project but more of a continuous process of asking questions. Secondly, scientific thinking was perceived as being the ability to find and set interesting research questions. One needs to find the gap in the existing knowledge and to be able to relate one’s research to the work of other people. In understanding the work of other people, it is not enough to familiarise oneself with the results of the research; it is also important to understand the basis of their research: what the objectives and limitations are of their research process. Thirdly, asking questions means questioning and adopting a critical attitude. It is not enough to settle for the conclusions reached. A critical attitude means also being able to analyse the argumentation and question the choices made during the research. (Ibid, 39-40.)

With these clearly philosophy-related challenges found in doctoral studies, it seems evident that the philosophy of science has meaningful connections to research also in the engineering sciences, although they are often not easily recognised. Peltonen (2005, 46) concludes by stating that philosophical thinking skills can help the growth from Master graduate to independent researcher by motivating and helping the individual to find interesting research questions, and subsequently to defend and to publish his/her research. It may not affect the quantity of research, but it can affect the quality of it.

4.3. Summary

The objective of scientific doctoral education is to train people in the art of scientific inquiry so that they are capable of an independent and critical production of scientific knowledge. This chapter has briefly introduced the Finnish doctoral education system and pointed out some general, national challenges in doctoral education, such as the need for clearer policies for recruitment and supervision, and better introduction and supervision.

Doctoral students in engineering were noted to experience that the content of their supervision was worse than doctoral students in any other discipline. The supervisor’s interestedness, methodological and theoretical supervision, and constructive criticism were especially perceived to be weak in the engineering sciences. (Hiltunen & Pasanen 2006). Peltonen (2005) identified three areas of challenge in doctoral studies in engineering: choosing and using research methods, publishing, and internalising the mode of scientific thinking. Moreover, Lahenius and Martinsuo’s (2011) study results suggest that in current doctoral education in engineering, scientific thinking skills develop through indoctrination into the community culture rather than through explicit teaching or supervision.

All of these philosophy-related challenges in doctoral studies suggest that the philosophy of science also has meaningful connections to research in the engineering sciences. However, these are often not easily recognised and thus not explicitly dealt with. These findings will help to interpret the meaning of the research findings and are revisited in the discussion of the results in Chapter Nine.

5. Research methods in this study

> *The study of paradigms … is what mainly prepares the student for membership in the particular scientific community with which he will later practice. Because he there joins men who learned the bases of their field from the same concrete models, his subsequent practice will seldom evoke overt disagreement over fundamentals. Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice. That commitment and the apparent consensus it produces are prerequisites for normal science, i.e., for the genesis and the continuations of a particular research tradition. (Kuhn 1996, 10-11)*

This study naturally also follows a paradigm and assumes some rules and standards of scientific practice. This chapter introduces the philosophical and methodological views and choices adopted and executed during the research process.

5.1. The research problem and philosophical commitments

Chapters Three and Four indicate that the discussion about the philosophy of engineering science is quite young and not very comprehensive. Although topics within the philosophy of technology and philosophy of engineering have been discussed more and for a longer time, these discussions are not directly transferable to the context of engineering science. Much of the discussion is based on philosophical or theoretical analyses, and empirically based studies are lacking to a large extent.

Finnish doctoral education has previously been studied mostly from the sociological and pedagogical perspectives with little, if any, attention given to the philosophical aspects. The findings concerning doctoral education suggest that forming a comprehensive picture of the philosophical questions and assumptions in engineering science studies is also difficult at an individual level. Experiences of insufficient theoretical and methodological supervision imply that the supervisors lack either a personal view on these issues or the language to communicate their view to their doctoral students. In either case, this indicates that the explicit shared understanding about the philosophical grounds is also lacking.

This study therefore strives to understand and describe what is considered to be science, scientific inquiry and scientific knowledge in engineering science; and how this is expressed in doctoral dissertations. It thus seeks to comprehend the essence and challenges of knowledge and knowledge creation processes in Finnish engineering science.

The main research question to be answered is:

What is engineering science like as a scientific discipline?

The question is approached with the help of the following three related subsidiary research questions:

I. What are the essential features of engineering science?
II. What kind of philosophy of science does engineering science entail?
III. What sort of challenges does engineering science pose for junior researchers?

The subject is studied from the viewpoint of a descriptive philosophy of science. It focuses on the nature of knowledge and knowledge creation processes with the intention of describing them as they are rather than how they should be. The temporal focus is on the latest research and what could be called modern engineering science. Although the study is organised in the form of a single-case study, with one university of technology as the case, it is argued that with a good case selection strategy, the findings can actually help to generate a theory applicable to a national context.

As a more practical contribution, the study also addresses the question of doctoral education's role and success in developing the scientific thinking of doctoral candidates.

5.1.1. The phenomenon under scrutiny

Science is a human activity. The conception of science refers to the way humans view this activity. It is thus very much a phenomenon belonging to the realm of the mind instead of to the natural world.

The phenomenon under study is the scientific nature of engineering science. It is the aim of postgraduate studies to develop doctoral candidates' understanding of science in their field to the degree in which they can independently follow and also conduct scientific research. This understanding is also expected to be reflected in their doctoral dissertation, which they publicly defend. Naturally, the view of science of a scientist continues to develop for the rest of his or her life. This development, however, results more often from personal experience even outside of the academic community than from systematic training. Thus, in this study it is assumed that the basic paradigm of the discipline is planted in the minds of novices during their graduate and, especially, doctoral studies.

The phenomenon is considered to be both personal and communal. Each doctoral graduate has a personal view of engineering science, but in this study it is assumed that there is also a common view of engineering science shared by the academic community of engineering science or its subgroups. Kuhn (1996, 182) called this "a paradigm or a disciplinary matrix of the field." It is partly explicit and partly implicit. Also, outsiders to the academic community of a particular field may have an idea about the science practiced within the field, but this layman's conception of science in engineering science falls outside the scope of this study.

5.1.2. Epistemological and ontological assumptions

As the phenomenon under study, the scientific nature of engineering science, is considered to belong to the realm of the mind, the hermeneutical dialogue, which is used for interpreting the meanings of certain occasions or understanding the human mind, is considered to be the appropriate approach for the study. Thus, the study is committed to the idea that nature can be explained but humans need to be understood (see e.g. von Wright 1971). The knowledge obtained in this study pertains to doctoral students', pre-examiners' and opponents' perceptions of scientific practice and scientific knowledge. It is not about discovering a stand-alone object called engineering science, which could then act as a normative model for practitioners aiming for it. Answering the research question "What is engineering science like as a scientific discipline?" is about answering the question "How do the practisers of engineering science perceive the philosophical nature of their actions and results and why do they do so?". This is the kind of idea that cannot be established by observation and experiment, but instead needs to be grasped through reflective understanding (von Wright 1971, 8). Therefore, the research follows the Aristotelian tradition and hermeneutic orientation to research.

Kannisto (2002, 343) describes hermeneutic inquiry as searching for truth about tradition. Although a person's intentions and the behaviour elicited by those intentions are always unique, they can only be understood within the context of a certain community. On the one hand, personal perceptions depend on this communal perception; on the other hand, they contribute to it. This study contains the epistemological assumption that knowledge about the communal perception can be obtained by studying personal perceptions, from which can be found the shared commitments and behavioural rules that give the rationale to personal interpretations. However, this knowledge is also an interpretation, namely that of researcher's, so the underlining epistemology can be said to be more subjectivist than objective if the objective epistemology is understood to discover the governing laws behind the phenomenon.

Naturally, the stakeholder groups studied, namely doctoral students, pre-examiners and opponents, are not the only stakeholders in the scientific community. Thus, the interpretation cannot be claimed to be the "only truth" about the phenomenon. Nor it is the "whole truth," as all interpretations are unfinished, provisional and incomplete (Denzin 2002, 362). Just like a mountain needs to be climbed one step at a time, this study aims to serve as the first step towards understanding the studied phenomenon. The empirical data is gathered in a certain setting, namely a technical university; yet the interpretation is assumed to be to some extent transferable to the national context. This includes the assumption that it is not meaningful to talk about the philosophical nature of science at one single university, especially in the Finnish context where universities are rather homogenous and well connected to other universities both nationally and internationally.

On the ontological side, this study holds the eclectic view that there exist things on both an observable level and beyond (realistic ontology), but that there also exist man-made theoretical entities that are constructed to act as aids but do not exist in the real world (constructivist ontology). The phenomenon under study is thought to belong to the latter category, as it is strongly dependent on the community in which it is studied, and it changes in tandem with the changes in the community. Thus, the ontology of this study regarding the subject of study can also be said to be relativist.

5.1.3. Purpose of the study

As Habermas (1971) might comment, this study serves a practical cognitive interest with the aim of achieving an intersubjective understanding of the phenomenon. This understanding is directed towards the attainment of consensus among the actors in the tradition and enables action-oriented self-reflection. (Ibid, 310.) In this case, the consensus can bring along with it opportunities to advance the three realms of universities: research, education and societal interaction.

Although engineering science seems not to have a clear and explicit shared understanding concerning aims and principles, knowledge creation of a high standard has been executed for decades. Following Kuhn’s (1996) ideas, engineering science can be perceived as being in a pre-paradigmatic stage, where several competing paradigms (natural vs. social sciences type of inquiry, research vs. design activities) are simultaneously present. These rival thinking-models are passed on from one generation to the next mainly through indoctrination and are thus rarely questioned. In a situation like this, a constructive discussion about the basic principles of the field is difficult.

For a young scientist, the adoption of a paradigm and comprehension of the rules of the scientific game in the field is challenging due to the implicit nature and lack of discussion about the philosophical grounds of the field. Paradigm-acquisition through indoctrination may also drive away individuals who would like to question or criticise some aspects of the field. These individuals are likely to have a considerable contribution to the community due to their diverse viewpoints. One example of a group of individuals like this in the engineering sciences are women, who are strongly underrepresented in the field, as the field portrays itself as the world of gadgets and machines, where the users and the related ecological and ethical aspects are easily forgotten or at most represented as minor problems.

In order to function better in knowledge creation and to serve society better, science must be able to critically reflect upon its procedures. This also applies to the engineering sciences. From an economical viewpoint, a better explication of the paradigm and conception of engineering science may even shorten the lead times of education at undergraduate, but especially graduate and doctoral levels. Improved understanding about the theoretical and methodological questions results in better supervision of the students, which is then realised in both the quality and number of graduates.

5.2. Methodological framework

The aim of understanding and describing the philosophy of science in engineering science is achieved mainly by means of empirical research, although some level of philosophical analysis is also required. As an empirical inquiry, this type of study belongs to the realm of science and technology studies.

The cognitive interest in this study is practical, and the orientation is hermeneutic. The process follows the general lines of qualitative research and applies the method of qualitative content analysis.

5.2.1. Science and technology studies

Science and technology studies comprise an interdisciplinary field of research which studies science and scientific activity. The field consists of multiple viewpoints stemming from the subjects of sociology, history, philosophy or psychology of science. Scholars in the field have differing backgrounds, with some originating from the so-called “parent disciplines” (e.g., sociology) and specialising in the study of science; whereas others come from natural sciences and are interested in pursuing and studying their own activities. This diversity also shows up in the theoretical backgrounds and methods used in the field. (Kiikeri & Ylikoski 2007, 9.)

Research in science studies can be either normative or descriptive. An example of normative research is the type of philosophy of science that tries to define how scientific research ought to be done in order for it to be scientific. Descriptive research of science does not aim at giving recommendations, but instead attempts to understand and describe scientific products, processes and activities as they are. This, however, is not simple, as many of the concepts in the field are in normal language inherently normative. This applies for instance to the concept of “fact” as calling something a fact is not merely a description of that something, but rather already entails a judgment about the truthlikeness and thus also acceptability of that statement. In descriptive science studies, this may cause distortion in an interpretation, as the aim is also to look at the epistemological and methodological claims from the perspective of an outsider in order to understand the dynamics of the inquiry and argumentation processes. Still, this does not mean that the researcher accepts all views as equally good or rational, s/he simply does not have to make those judgments. (Ibid, 26.)

The descriptive studies pursued in the realm of the philosophy of science follow the ideas of philosophical naturalism. This is characterised by four attributes: 1) studying the processes rather than of the end products of science, 2) being descriptive rather than normative, 3) taking methodological models from the empirical disciplines rather than from analytical philosophy, and 4) emphasising the context of scientific discovery alongside the context of justification. (Paavola 2003, 33.) In Paavola’s opinion, overemphasising the naturalistic approach to philosophy may cause the very nature of philosophy as a theoretical research to disappear; thus, also the useful division of labour between empirical research and normative philosophy is lost. Although this study concentrates on the descriptive and empirical exploration of engineering science, it is hoped to be more of an aid for than an obstacle to the normative approach towards the same issues.

5.2.2. Qualitative content analysis

This study follows the hermeneutical tradition but receives some assistance from the data analysis methods in U.S. qualitative research. Thus, the interpretive paradigm is constructivist-interpretive (see Table 2 on page 24). The chosen data analysis method of qualitative content analysis is not seen as replacing the hermeneutic cycle, but instead helps to execute and document the interpretation process in a more systematic manner.

Content analysis often refers to a certain method of organising qualitative data with quantitative means. This method fits the positivist paradigm of qualitative research and was developed to meet the standards of the scientific method; i.e., objectivity, reliability and validity. (Neuendorf 2002, 10-14.) The advocates of this kind of content analysis do not usually perceive the non-quantitative content analysis as feasible (see e.g. ibid., 14). Ryan and Bernard (2003, 282-284) call this type of content analysis “Classical Content Analysis.”

According to the constructivist-interpretive paradigm, content analysis is understood differently. There, the term can refer either to a certain method or to a loose framework of different processes of analysis. (Tuomi & Sarajärvi 2009, 91.) Tuomi and Sarajärvi (2009, 101) link the perception of qualitative content analysis as a method to the U.S. tradition of qualitative research, but it remains unclear whether they assume that it is thus based on positivistic philosophical thoughts. Nevertheless, in this study, qualitative content analysis is perceived as a research method which is also compatible with the constructivist-interpretive paradigm and hermeneutical tradition of qualitative research.

Miles and Huberman (1994, 10-12) define qualitative data analysis as consisting of three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification. Data reduction includes the processes that sort, focus and organise data in such a way that final conclusions can be drawn and verified. It consists of analytic choices of selecting, simplifying, abstracting and transforming the data from the original mass into a condensed form. Miles and Huberman define a data display as “an organised, compressed assembly of information that permits conclusion drawing and action.” They note that designing data displays has a data reduction implication. Thus data displays can perhaps also be defined as the end products of data reduction. A qualitative analysis commonly uses data displays such as matrices, graphs, charts and networks. Based on the reduced and displayed data, the researcher decides what things mean. During the analysis, the researcher notes regularities, patterns, explanations, causal flows, propositions or other configurations which enable him or her to answer the original research question. Conclusions also need to be verified to convince others about their quality; i.e., truth and utility.

The process of a typical case of classical content analysis involves the following seven steps: first, deciding upon the theoretical framework; second, operationalising measures; third, creating a coding scheme; fourth, sampling the data; fifth, coding the data; sixth, tabulating the statistical results; and seventh, reporting these statistical results (see e.g. Neuendorf 2002, 50-51).

Qualitative content analysis resembles classical content analysis in the main data reduction tools used, namely coding. In qualitative content analysis, the coding scheme may be theory-based and created before coding, or it may also be grounded in data and created during the coding process.

A third option is to start with a tentative coding scheme derived from theory, but then to let the scheme develop as the coding process proceeds to take into account what arises from the data. (Tuomi & Sarajärvi 2009) This type of coding is sometimes called theory-guided or theory-directed coding (in Finnish: *teoriaohjautuva koodaus*). The process of theory-guided coding is somewhat similar to the coding grounded in data (also referred to as inductive content analysis). The difference is that with data-grounded coding, the concepts or “the names of the phenomena” arise from the data, whereas in theory-guided coding, the concepts related to the inquiry are previously known. (Ibid, 117.) However, the required selection of the concepts along with their relationships is not known beforehand (contrary to the case of theory-based coding), but emerges from the data instead.

In this study, the qualitative content analysis proceeds in the following stages:

1. Building the theoretical and the methodological framework of the study
    - Building an understanding about the phenomenon and its context based on the literature and previous research
    - Building an understanding about the kind of research to be conducted
2. Creating the tentative coding scheme with which to begin the coding
3. Collecting the data
4. Analysing the data
    - Reducing the data by theory-directed coding, memoing and other applicable means
    - Displaying the data in descriptions of the noted patterns, tables of presence/absence of certain aspects in primary documents and document families, concept maps of codes, etc.
    - Drawing and verifying conclusions: noting patterns, clustering, counting, noting relations between variables, etc.
5. Evaluating the quality of the research and research findings
6. Discussing the conclusions

A more thorough description of the data analysis as it actually occurred, along with the tools and procedures used in it, is provided in the next chapter.

5.2.3. Dissertations and statements as data

The most typical ways of collecting data in qualitative research are interviews, surveys, observations and use of different documents. These tools may be used alternatively, jointly or in different combinations depending on the research problem and resources. (Tuomi & Sarajärvi 2009, 71) Written documents used as research data can be subcategorised into private documents and public media documents. The use of private documents presupposes that the author can express himself/herself (and is even somehow at his/her best) in writing. (Ibid, 84) Documents are important material in qualitative research because they are often easy and cheap to access, they provide information that may not be available in spoken form and they offer historical insight (Hodder 2003, 156).

A dissertation is a text in which the doctoral candidate demonstrates his/her ability in scientific thinking. When a dissertation is evaluated, the manuscript is evaluated for consistency, critical treatment of objects, the quality of application of the scientific or artistic research method, novelty value and scientific significance. The assessment is done in two phases. In the preliminary examination, two pre-examiners provide the faculty council a statement regarding the acceptability of the scientific or artistic merit of the manuscript and whether it should be granted permission for publication as a doctoral dissertation. The actual evaluation of the doctoral dissertation is based on the public defence, after which the opponent(s) submit(s), either individually or jointly, a written statement concerning the dissertation to the faculty council, which then decides on the matters concerning the approval of and grade for the dissertation. (Tampere University of Technology Degree Regulations 2010, 29-31§.)

Argyris' and Schön's (1974) theory of action states that when "someone is asked how he would behave under certain circumstances, the answer he usually gives is his espoused theory of action for that situation. This is the theory of action to which he gives allegiance, and which, upon request, he communicates to others. However, the theory that actually governs his actions is this theory-in-use." (Argyris & Schön 1974, 6-7). When interviewing doctoral students and their supervisors about the connection between the philosophy of science and their research, Peltonen (2005, 26) noticed that some of the interviewees were puzzled about the concept of the philosophy of science. She also occasionally felt that the interviewees were thinking about what the interviewer was hoping to receive for an answer (ibid, 18).

Considering the nature of the dissertation as a demonstration of scientific thinking and the possible inability of doctoral candidates to express their philosophical views orally, the first set of data for this study was chosen to be obtained from the dissertations. As the purpose is to understand the conception of science as theory-in-use and not as espoused theory, the interviews or surveys were not considered to be a good option for data gathering.

Similarly, the pre-examiners' and opponents' statements were also thought to better represent the theory-in-use of the pre-examiners and opponents (i.e., the scholars in the field) regarding the central features and quality of the research than could, for instance, interviews or surveys. It was hoped that this second set of data could especially shine light on the challenges related to the engineering science research work. It was also thought that it could broaden the understanding of the phenomenon by complementing the views of novices with those of experts, and by expanding the scope from the views of Tampere University of Technology (TUT) researchers to the views of the international research community in engineering sciences.

5.2.4. Case-selection strategy

There has been a fair amount of discussion about whether case studies can be used for building theory and finding generalisable knowledge (see e.g. Flyvbjerg 2006). Eisenhardt (1989) has argued that case study is an appropriate research approach, especially in new topic areas, and may result in a novel and empirically valid theory. As her views stem from the positivist view of research, which holds the idea that a proper theory is something testable and generalisable across various settings, it can be concluded that Eisenhardt’s argument also supports that case studies can generate generalisable knowledge.

Flyvbjerg (2006) suggests that generalising is possible even on the basis of an individual case. His argument is based on the view that in the social sciences and study of human affairs, there are no strong, predictive theories, but only context-dependent knowledge. The idea of all knowledge being knowledge about specific cases implies that all situations are interpreted through context-dependent knowledge, and adding to this knowledge base can enhance our expert understanding of the situation.

Flyvbjerg also suggests that the strategic selection of cases increases the generalisability of a case study. He names four different case-selection strategies that serve different purposes of information production. The first and second case strategies, *extreme cases* and *maximum variation cases*, typically help one to obtain rich information that helps to clarify the deeper causes behind the phenomenon more easily than one’s looking into the average or most frequent features. The third type of case strategy, the *critical case*, has strategic importance with respect to the general problem. It is often either the “most likely” or the “least likely” instance for a phenomena to occur. Critical cases are well suited for falsification or verification purposes: if a hypothesis proves to be invalid for the most likely case or valid for the least likely case, we have a strong point against or in favour of the theory. The fourth and final case-strategy type, *paradigmatic cases*, have so-called “prototypical value.” They are instances which highlight the more general characteristics of the phenomenon in question. A paradigmatic case typically helps to establish a school for the domain of the concern, because it sets the standards for the occurrence.

This case-selection strategy is based on the idea that data are collected in a context of one university and interpreted in the context of Finnish engineering science. This study is organised as a single case study, with TUT being the case organisation. From the viewpoint of case-selection strategy, TUT is considered to be both a critical case of the “most likely” type and a paradigmatic case. The criticality of the case is related to challenging the claim that engineering science is a natural science (see subsidiary research question i). TUT makes a solid critical and paradigmatic case for several reasons. Engineering science in Finland has mainly been defined through educational institutions due to the lack of explicit, generally agreed upon philosophical definitions or characterisations. Thus, it is easier to select the data for this study accordingly instead of selecting certain research areas or professorships, as there are no obvious rules for this kind of inclusion or exclusion. At the moment, TUT is the only Finnish university that contains no other fields than engineering science[3]. Therefore, it is also the only Finnish university whose organisational culture is not governed by fields other than engineering science. The traditional areas of engineering science (civil engineering, mechanical engineering, electrical engineering and chemical engineering) are all represented at TUT, together with the newer fields typical to contemporary engineering science (industrial management, computer science, environmental engineering). This is not the case in smaller engineering units, the technical faculties of multidisciplinary universities, which are typically solely focused on a few areas of engineering science. TUT is also a “middle-aged” and average-sized university in the Finnish context, which makes its organisational culture and research areas somewhat stable and established. In other words, TUT is a university clearly focused on engineering science, but with a multitude of different research areas and engineering disciplines. This makes TUT a broad but clearly defined prototype of a higher education institute of engineering science in Finland.

5.3. Ensuring the quality of research

The quality of this research is evaluated against the seven questions of quality discussed in section 2.5.1 Aspects of quality, and is illustrated in Figure 3. In the philosophical and methodological framework at hand, the seven overarching questions are understood and refined as follows:

1. Question of truth-value: How is the credibility of interpretations enhanced? To what extent can the reader be sure that the interpretations are also credible to the respondents (here, the authors of the studied dissertations) and not only to the researcher?
2. Question of applicability: How is the sending context (the context in which the interpretations were made) described to the readers in order for them to make valid judgments about the transferability of results in the receiving context (the context in which the results are intended to be used)?

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[3] In Finland, architecture has traditionally been taught and researched in universities or faculties of technology and thus it is considered here as a part of the realm of engineering science, although recent reforms in Finnish universities have positioned architecture differently.

3. Question of consistency: How are the factors of possible instability of the phenomenon and the factors of phenomenal or design-induced change taken into account?
4. Question of neutrality: Can the results be corroborated by others? Is the process described in such a way that it is easy for others to follow what has been done and arrive at the same conclusions?
5. Question of publicity: Have the scientific community and the audience had the opportunity to familiarise themselves with and question the process and results of the inquiry? How are the results published? Is there anything that has been deliberately hidden from others?
6. Question of novelty: What is new about the research findings?
7. Question of utility: How can the knowledge gained through investigation be used in both scientific and practical work?

With respect to the question of truth-value, Maxwell (1992) distinguishes between three different kinds of validity: descriptive, interpretive and theoretical. The challenges commonly relating to descriptive validity concern the factual accuracy of the inquirer's account; i.e, whether what got recorded was actually what happened and whether every meaningful thing got recorded. This can be a challenge, especially when observations are used as a means to gather data. Descriptive validity is, however, not really in question when written documents are used as data, because the writing is not altered by the researcher in the data collection stage of the inquiry.

Interpretive validity concerns the accounts of meaning. To arrive at good interpretive validity, the accounts of meaning must be based on the conceptual framework of the respondents rather than on purely that of the researcher. (Ibid.) In terms of credibility, this means that the interpretations of the researcher are credible to respondents, and it is also a valid question regarding this study.

Theoretical validity refers to the function of the interpretation as an explanation of the phenomena. It has two aspects: the validity of the constructed concepts and the validity of the postulated relationships between them. (Ibid.) In this study, the question of theoretical validity also comes down to the question of credibility of the constructed interpretation and its elements.

In the positivistic research tradition, the question of applicability is often approached by discussing the generalisability of the results. This study belongs to the interpretive tradition, where applicability is more commonly addressed by discussing the transferability of results. The concepts of generalisability and transferability are not identical, but in this study they are not considered to be contradictory or incommensurable either. Thus, the concept of generalisability is also addressed more closely for two reasons. First, it is assumed that many readers are more familiar with the positivistic concept of generalisability than with the naturalistic concept of transferability; therefore, an analysis of the research quality from both angles is useful. Second, an analysis and conceptualisation consisting of different types of generalisability can be used as a tool for a more detailed analysis of quality in naturalistic research, too. However, from the naturalistic viewpoint, the different types of generalisability are not all related to the quality aspect of applicability, but some of them are more useful for judging the credibility or consistency of the research. The evaluation of the quality of the process and products of this study is presented in more detail in Chapter Ten.

5.4. Summary

This chapter presented the key research questions as well as the philosophical and methodological commitments made in the study. The primary research question "What is engineering science like as a scientific discipline?" is approached by means of three related subsidiary research questions: 1) What are the essential features of engineering science? 2) What kind of philosophy of science does engineering science entail? 3) What sort of challenges does engineering science pose for junior researchers? The subject is studied from the viewpoint of a descriptive philosophy of science.

The phenomenon under study is the scientific nature of engineering science. It is considered to be both personal and communal, as each doctoral graduate has a personal view of engineering science, but a common view of engineering science shared by the academic community of engineering science or its subgroups is also assumed to exist.

The research follows the Aristotelian tradition and hermeneutic orientation to research. It contains an epistemological assumption that knowledge of communal perception can be obtained by studying the personal perceptions, and find thus the shared commitments and behavioural rules that give rise to the rationale underpinning the personal interpretations. The empirical data has been gathered in a certain setting, namely one technical university. However, the interpretation is assumed to be to some extent transferable to the national context, involving an assumption that it is not meaningful to talk about the philosophical nature or science of a single university.

As an empirical inquiry, the study belongs to the realm of science and technology studies. It focuses on the nature of knowledge and knowledge-creation processes with the intention of describing them as they are rather than how they should be. The interpretive paradigm is constructivist-interpretive, whereby the chosen data analysis method of qualitative-content analysis is not seen to replace the hermeneutic cycle but rather to help to execute and document the interpretation process in a more systematic manner.

As the purpose of this study is to understand the conception of science as theory-in-use and not as espoused theory, the dissertations were considered to demonstrate the scientific thinking better than interviews or surveys, for example. Statements from pre-examiners and opponents were chosen to broaden the understanding of the phenomenon by complementing the views of novices with those of experts and by expanding the range of views from TUT researchers to the international research community in the engineering sciences.

Case-selection strategy is based on the idea that data is collected in the context of one university but subsequently interpreted in a larger context. The study is organised as a single case study with Tampere University of Technology (TUT) as the case organisation. The case-selection strategy considers TUT to be a critical case of the “most likely” type, but also a paradigmatic case (see Flyvbjerg 2006 for the different case types).

Finally, Chapter Five presented the plan for assuring the quality of the research with the help of seven quality aspects. This scheme will be implemented in Chapter Ten, where the process and product of this inquiry are evaluated. This chapter forms the basis on which the research process introduced in Chapter Six lies.

6. The research process

> *In speaking about qualitative analysis, we are referring not to the quantifying of qualitative data but rather to a nonmathematical process of interpretation, carried out for the purpose of discovering concepts and relationships in raw data and then organizing these into a theoretical explanatory scheme. (Strauss & Corbin 1998, 11)*

This process of discovering and organising is described in this chapter. It is preceded by the description of the data selection process.

6.1. Collecting the data

With dissertations and statements chosen as the format for collecting the research data, questions arose of how many and which ones to study. There seemed to be no justifiable reason for choosing dissertations and statements which would be unrelated to each other. Thus, an appropriate selection process would be to choose the dissertations and then take the statements related to them, or vice versa.

As documents, dissertations are much larger and therefore also suspected to be more informative from the viewpoint of this study than are statements, so the selection process was directed towards the dissertations. The following sections first introduce the selection process and the resulting collection of dissertations and then outline the collection of statements that accompanied the dissertations.

6.1.1. Selecting the dissertations

The researcher conducted a preliminary study of 103 dissertations in the summer of 2007. The orientation and scope, however, were much narrower than those of this study. Nevertheless, the preliminary study suggested that a more thorough study of 50 dissertations would likely be enough to yield a sufficiently rich picture of the phenomenon, but also a resource-wise sensible extent of data. Thus, the researcher decided that the selection of 50 dissertations was to be the starting point of the study, still keeping in mind that more dissertations could be added to the selection if the analysis suggested the need for that in order to reach theoretical saturation (for more on theoretical saturation, see e.g. Strauss & Corbin 1998, 212).

TUT has a database (DPub) for electronic dissertations where doctoral candidates may choose to publish their dissertations. The oldest dissertation in the database is from 1996, but all the others are from the 21st century. In 2010, two-thirds of all dissertations completed at TUT were included in the database. Selecting dissertations from DPub provides easier access to the data, which is already in electrical format and can thus be analysed with the help of suitable qualitative research software. This, along with the resource benefits gained from using the software, enabled the inclusion of a larger number of dissertations in the study, provided that the selection was not biased in a way that would remarkably hinder the drawing of conclusions about phenomena in general.

Following Peltonen's (2005) notion that the philosophy of science is viewed differently in different departments, the representation of different faculties in the DPub database with respect to all the dissertations completed in TUT had to be verified. It was noted that during the years 2008-2010, the distribution of faculties within the electronic dissertations and all the TUT dissertations (which in practice represent doctors who have already graduated) is very similar, with the difference in relative representation being at the most three percentage points. However, following the exact faculty distribution in either DPub or in all dissertations would have meant that only one dissertation from the smallest faculty would have been admitted into the study.

As the objective of this study was to build a comprehensive understanding and not to find statistical correlations, it was decided that the biggest faculties would become slightly underrepresented and the smallest faculties slightly overrepresented in the selection of dissertations for the study. Another reason for selecting four dissertations from the Faculty of Built Environment was to ensure that the area of both architecture and civil engineering would be included. The selection consisted of the following[4]:

- 21 dissertations from the Faculty of Computing and Electrical Engineering
- Ten dissertations from the Faculty of Science and Environmental Engineering
- Nine dissertations from the Faculty of Automation, Mechanical and Materials Engineering
- Six dissertations from the Faculty of Business and Technology Management
- Four dissertations from the Faculty of Built Environment

The distribution of faculties among 1) the DPub dissertations from 2008-2010, 2) all PhD degrees awarded in 2008-2010 and 3) in the research data is presented in Figure 11. Of this assortment, the oldest dissertation in the selection was publicly defended in March of 2010, and the newest in September of 2011.

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[4] Originally, the selection had 20 dissertations from Faculty of Computing and Electrical Engineering (CEE) and seven dissertations from the Faculty of Business and Technology Management (BTM). During the analysis, it turned out that one of the seven was in fact done in the CEE but incorrectly marked in DPub as BTM. The dissertation was decided to be kept in the data selection, and thus the distribution of dissertations according to faculty changed slightly. This did not, however, alter the selection criteria or the representation of different faculties notably, as CEE still is slightly underrepresented and BTM did not become underrepresented in the data.

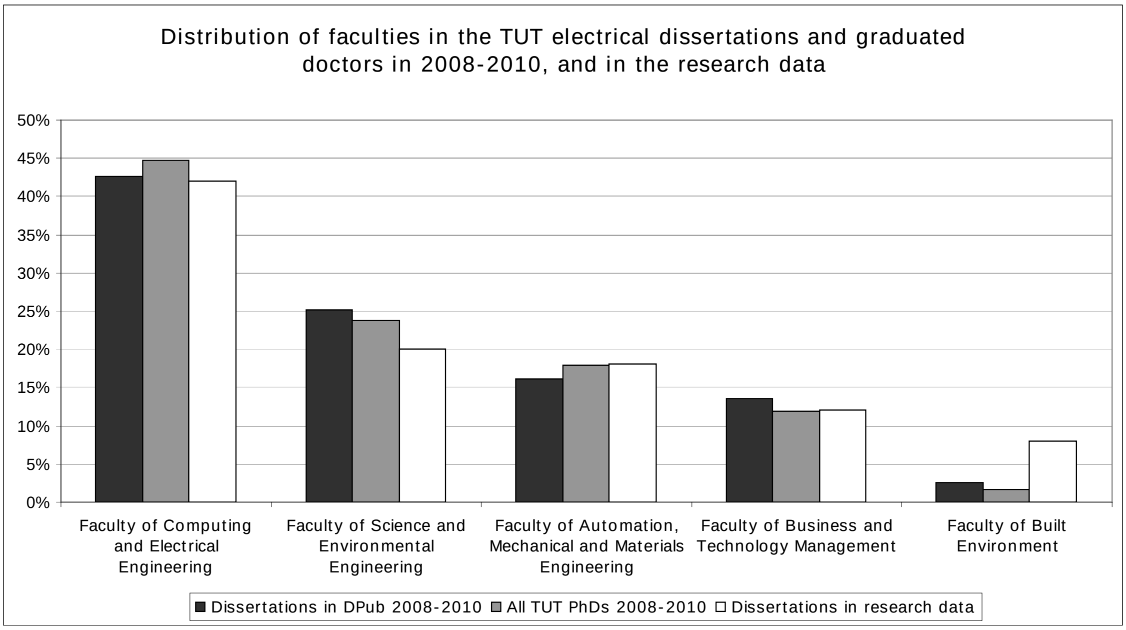


Figure 11. Dissertations in DPub, all TUT PhD degrees awarded, and the proportion of dissertations in the data sample in different TUT faculties

The desire to understand the current state of affairs resulted in the thought that the dissertations included in the selection ought to be fairly new. Thus, the author decided to make the selection based on the database content of 2 September 2011 and to choose the newest possible dissertations. The dissertations were arranged according to the faculties in the descending order of the date of public defence. Then, a preliminary number of candidates from each faculty were chosen, and the selection was checked against the timeline, gender distribution and proportion of monograph and compilation dissertations.

Gender distribution was analysed by comparing the share of women in the DPub dissertations from 2008-2010, all PhD degrees awarded in 2008-2010 and the selection for this study. The gender of doctoral candidates publishing dissertations in DPub was concluded by the researcher from the first names of the candidates. All the cases with uncertainty; i.e., some unfamiliar foreign names, were left out of the examination. This suggests that women are represented in the DPub database quite similarly to the total number of doctoral graduates (and thus the total number of dissertations). They are, however, overrepresented in the selection where their share is 36 %. This may be due to the slight underrepresentation of the male-dominant Faculty of Computing and Electrical Engineering or to the temporal location of selection— in 2010, the share of women doctoral graduates was 30%, which is slightly higher than in most years. The distribution of gender among the DPub dissertations from 2008-2010, all PhD degrees awarded in 2008-2010 as well as those awarded in the research data are elaborated upon in Figure 12. The key figures of the selection of the dissertations are presented in Table 12.

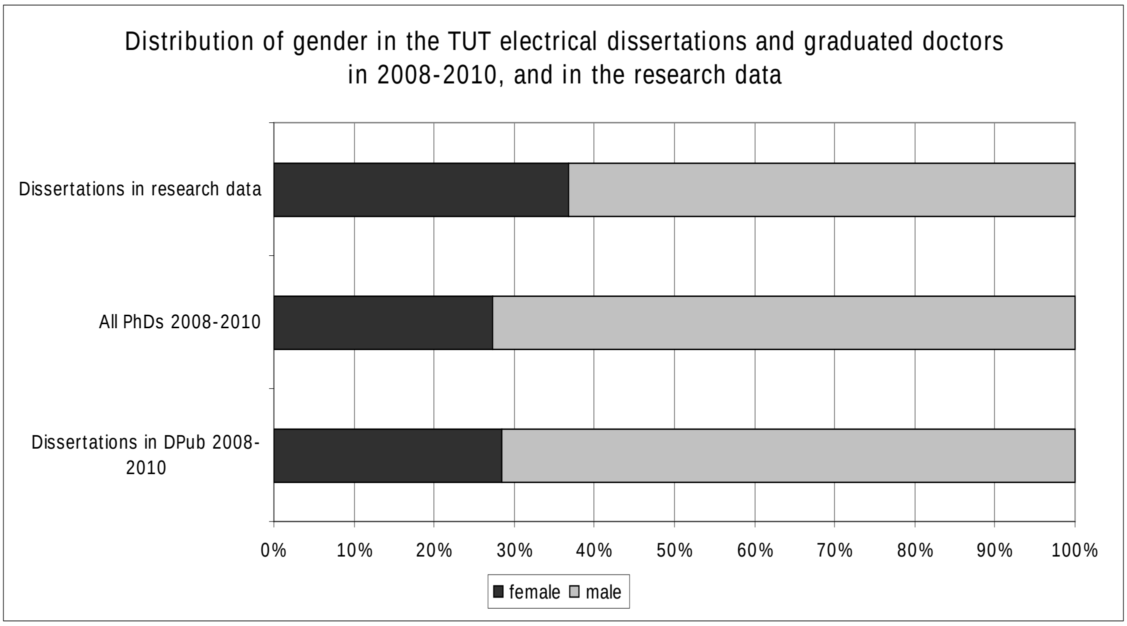


Figure 12. Dissertations in DPub, PhD degrees awarded, and the proportion of dissertations in the data sample according to the gender of the author

Table 12. Selection of a dissertation in terms of the relevant faculty, gender of the candidate, format of the dissertation and the date of public defence

Selection of dissertations from the DPub database (N=50)		
Faculty		N (share of all)
	Faculty of Computing and Electrical Engineering (CEE)	21 (42 %)
	Faculty of Science and Environmental Engineering (SEE)	10 (20 %)
	Faculty of Automation, Mechanical and Materials Engineering (AMM)	9 (18 %)
	Faculty of Business and Technology Management (BTM)	6 (12 %)
	Faculty of Built Environment (FBE)	4 (8 %)
Gender of author*		
	Female	18 (36 %)
	Male	32 (64 %)
Format of dissertation		
	Monograph	14 (28 %)
	Compilation	36 (72 %)
Dates of the public defence of the dissertations: from March of 2010 through September of 2011		

The selection of 50 contained 14 monographs (28%) and 36 compilation dissertations (72%). Unfortunately, comparing this ratio to that of all the dissertations from TUT is not possible, as the information is not readily available. However, it is not too unlike the figures reported by Hiltunen & Pasanen (2006), where in 2005, 64 % of the doctoral students in engineering sciences worked on compilations. As the compilations have become increasingly popular, it is reasonable to assume that the division between monographs and compilations in the selection is quite close to that of all the dissertations. There were both monographs and compilations among the dissertations from each faculty.

6.1.2. Demography of the statements

The selection of the dissertations in turn defined the selection of the statements. TUT Degree regulations mandate that two pre-examiners must be appointed to each dissertation manuscript. In one of the fifty dissertations included in the data, the pre-examiners gave a joint statement. Thus, the statements data included 99 pre-examination statements. Each dissertation is also appointed one or two opponents, who could render individual statements, but at least in all cases in this study, the opponents chose to provide a joint statement. (TUT Degree regulations 2010, 29-31§.) The number of opponents' statements in the statements data was therefore 50, and the total number of all statements was 149.

In 22 cases, the dissertation was evaluated by one opponent, and in 28 cases by two. Consequently, the total number of pre-examiners and opponents was 177, although this figure includes some people twice, as it is quite usual to have one of the pre-examiners as an opponent. Over half of the pre-examiners and opponents came from foreign institutions. The background organisations of the pre-examiners and opponents can be found in more detail in Figure 13. Faculties differ slightly in this respect, with the Faculty of SEE having the least amount of Finnish pre-examiners and opponents, and the Faculty of BTM having the most. These two faculties also had the largest percentages of reviewers from outside of universities and research institutes, but the Faculty of SEE used mostly foreign reviewers, and the Faculty of BTM only used Finnish non-university reviewers. These differences are illustrated in Table 13. The other institutions were mostly private companies. One opponent came from a Finnish university of applied sciences.

Table 13. The background of the pre-examiners and opponents in different faculties

Faculty	Finnish university or research institute	Other Finnish institution	Foreign university or research institute	Other foreign institution
AMM	40 %	3 %	49 %	9 %
SEE	34 %	3 %	47 %	16 %
FBE	33 %	8 %	58 %	0 %
CEE	38 %	8 %	50 %	4 %
BTM	50 %	20 %	30 %	0 %
total	**39 %**	**7 %**	**47 %**	**6 %**

In one case, the pre-examiner had a foreign name but came from Finnish company in Finland. In Table 13, he is located according to the organisation. Adjunct professors were judged by their employer and not by the university with which they had the affiliation.

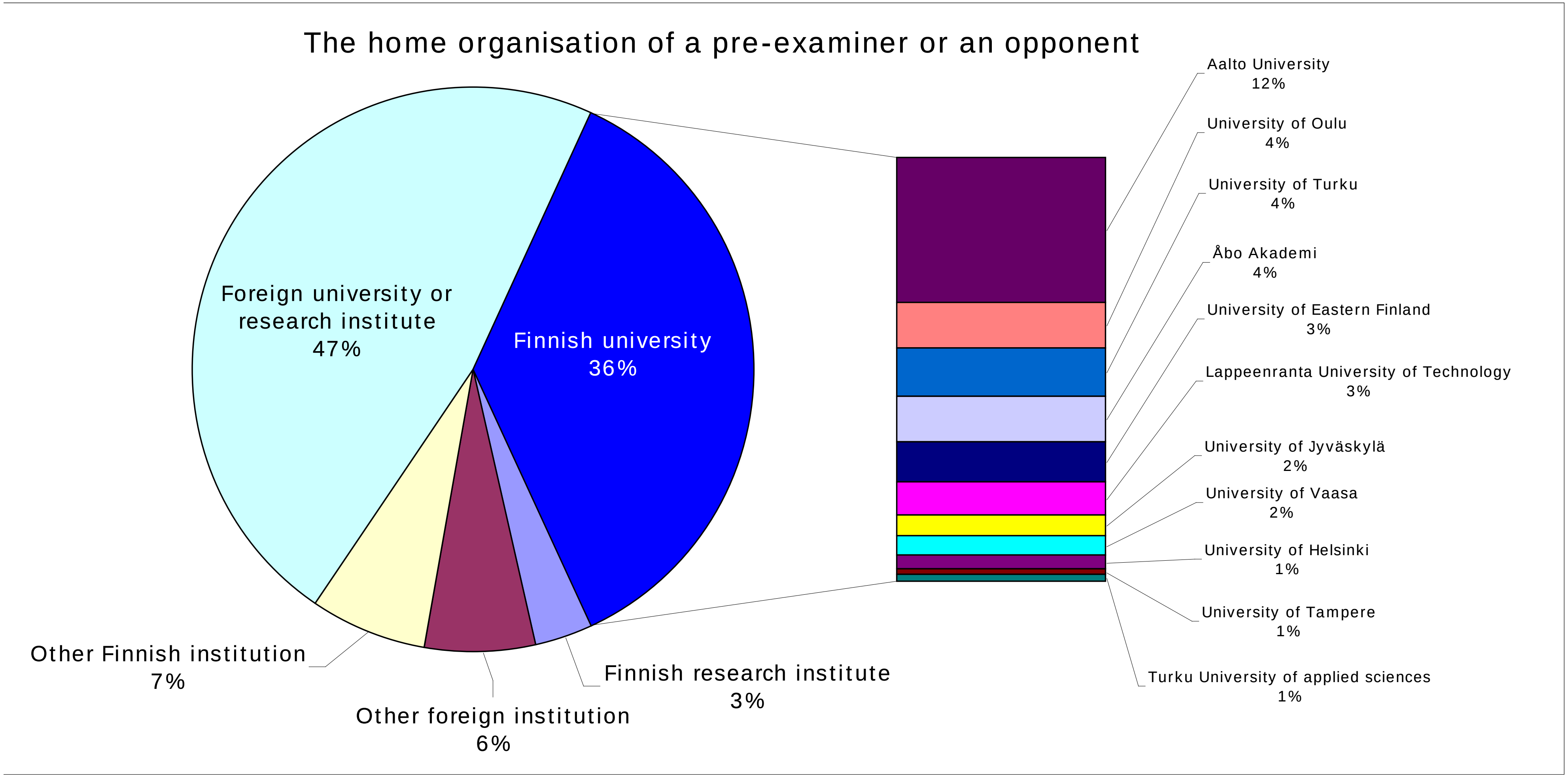


Figure 13.Home organisations of the pre-examiners and opponent

6.2. Analysing the data

It was decided that the data would be analysed with the appropriate software (ATLAS.ti). The data were coded according to the principles of theory-directed coding in two stages: first the dissertations, and then the statements. Counting the frequencies of codes and categories and exploring their distributions in documents and families of documents proved to be the most useful aids in both the reduction of data and drawing of conclusions. The following sections describe the principles and procedures of data analysis.

6.2.1. Computer-assisted qualitative analysis

Nowadays, using computers in qualitative analysis is more the rule than the exception. The choice of software depends on the type of data and analysis, but also on the computing skills of the researcher (Weitzman 2003, 322-323). The data management and analysis software used in this study was ATLAS.ti. It was chosen because of its familiarity to the researcher and suitability for the type of analysis at hand.

Weitzman (2003) classifies ATLAS.ti as a code-based theory building and conceptual-network-building software. Code-based theory builders are based on a code-and-retrieve model, which allow the researcher to apply category tags (i.e., codes) to chunks of data and then retrieve and display the chunks according to one's coding. They go, however, beyond the functions of mere coding and retrieving and have features that support the theory-building efforts. These features include the representations of the relations among the codes, building of higher-order classifications and sophisticated search-and-retrieval functions. Conceptual network builders are programs that allow the creation and analysis of network displays. (Ibid, 320-321.)

The benefits sought by the use of scientific software were the same as in many other cases: the effective management of data and the analytic possibilities offered (see e.g. Fielding and Lee 1998, 56-59). The effective data management of ATLAS.ti arises mostly from the code-and-retrieve related features, which allow for quick, easy and reliable access to the coded data. The analytic possibilities arise from the theory-building-supporting features, which allow for a quick way to display data in different formats, such as tables, networks and hierarchies.

The commonly named concerns arising from the use of computers in qualitative analysis are twofold: the fear of losing the closeness to the data and the fear of the software driving the methodological choices of the researcher. Losing the closeness to the data could be a result of the temptation to skim the surface of the data instead of becoming thoroughly familiar with it. (Weitzman 2003, 332; Fielding & Lee 1998, 73.) This seems to be a justifiable concern, especially if the now readily available features of automatic coding are used in an inappropriate manner. The possibility of software having an impact on the researcher's methodological choices comes along with the fact that software developers bring assumptions, conceptual frameworks and even ideologies to the development of their products (Weitzman 2003, 332). If the researcher is not aware of this and if her own methodological grounds and ideas are not solid, it is possible that the researcher will be steered in the wrong direction. However, according to Weitzman, there are often ways to adapt the program to one's own purposes and to work around the issues that seem to have a misleading effect.

In this research, the ideas to be coded and recorded were such that automatic coding was not possible and thus not used. In practice, coding the data required a rereading of the whole data set for each thematic round of the analysis. This means that the dissertations were read through approximately seven times. Having the possibility to retrieve codes and passages easily and move quickly from one document to the next in this case could have even enhanced the closeness of the data instead of diminishing it, as sometimes the dwelling on the details of a certain dissertation drew the focus temporarily away from the phenomenon studied. The analysis followed the ideas of theory-guided coding, where the outline of the conceptual framework was adopted from the theory. It could thus not be affected by the software. The use of the theory-supporting features of the software was quite limited and used mainly for data reduction and display, instead of for finding relationships between codes. In this respect also, the possibility of the software guiding the analysis is rather small.

6.2.2. Data reduction and display

According to the principles of theory-directed coding, the author began the reduction of the data by creating a tentative coding scheme based on the literature. The tentative coding scheme used in the analysis of dissertations is presented in Figure 14.

As the coding of the dissertations proceeded, the coding scheme changed. The changes were due to three different factors: 1) what was emerging from the data; 2) the fact that the categorisations included in the tentative scheme gained no empirical support; and 3) inclusion of new viewpoints from the literature, as the ideas emerging from the data concurrently led to the inclusion of new viewpoints into the theoretical overview of the phenomenon. Some aspects of the coding scheme remained quite similar to the tentative scheme and others were altered completely. The final coding scheme is presented in Figure 15.

The greatest changes to the coding scheme emerging from the data pertained to the inquiry process. The expectation derived from the literature was that of a philosophical analysis of the choices made before the actual empirical work was executed; such an analysis was generally not present in the dissertations. Instead, the process of empirical inquiry was presented in practical terms, describing more what had actually been done than why it had been done. The methodological choices for the whole inquiry process were also seldom presented as such, but often focused on one or two stages of inquiry. Perhaps the dissertation authors were following an idea that certain methodological commitments for other stages of inquiry logically follow from the other choices, and thus do not need to be elaborated upon.

With respect to the aspect of evaluation in the coding scheme, the modifications from the tentative coding scheme to the final one arose from the data but were conceptualised mainly through literature. The original idea of separately evaluating the process and product of scientific inquiry remained, but it was realised in the dissertations through the discussion of the different aspects of quality rather than the clear differentiation of the evaluation of process and evaluation of products.

In practice, the coding of dissertations was executed in six rounds. The first round was an attempt to apply the entire tentative coding scheme to the data at once. As that proved to be problematic, the coding was appraised one aspect or theme at a time. Depending on the theme, the coding varied from a rather straightforward application of the categories of the tentative coding scheme to a virtual grounding of the coding in the data. In the areas which underwent significant changes to the coding scheme, all applicable quotations were first marked with one code. Then, those marked quotations were compiled as a new document, which was then worked through over and over again until the satisfactory categories and codes were arrived at. The proceeding of the coding process was documented in a log. A more detailed illustration of the practical proceeding of the coding is presented in Appendix 2.

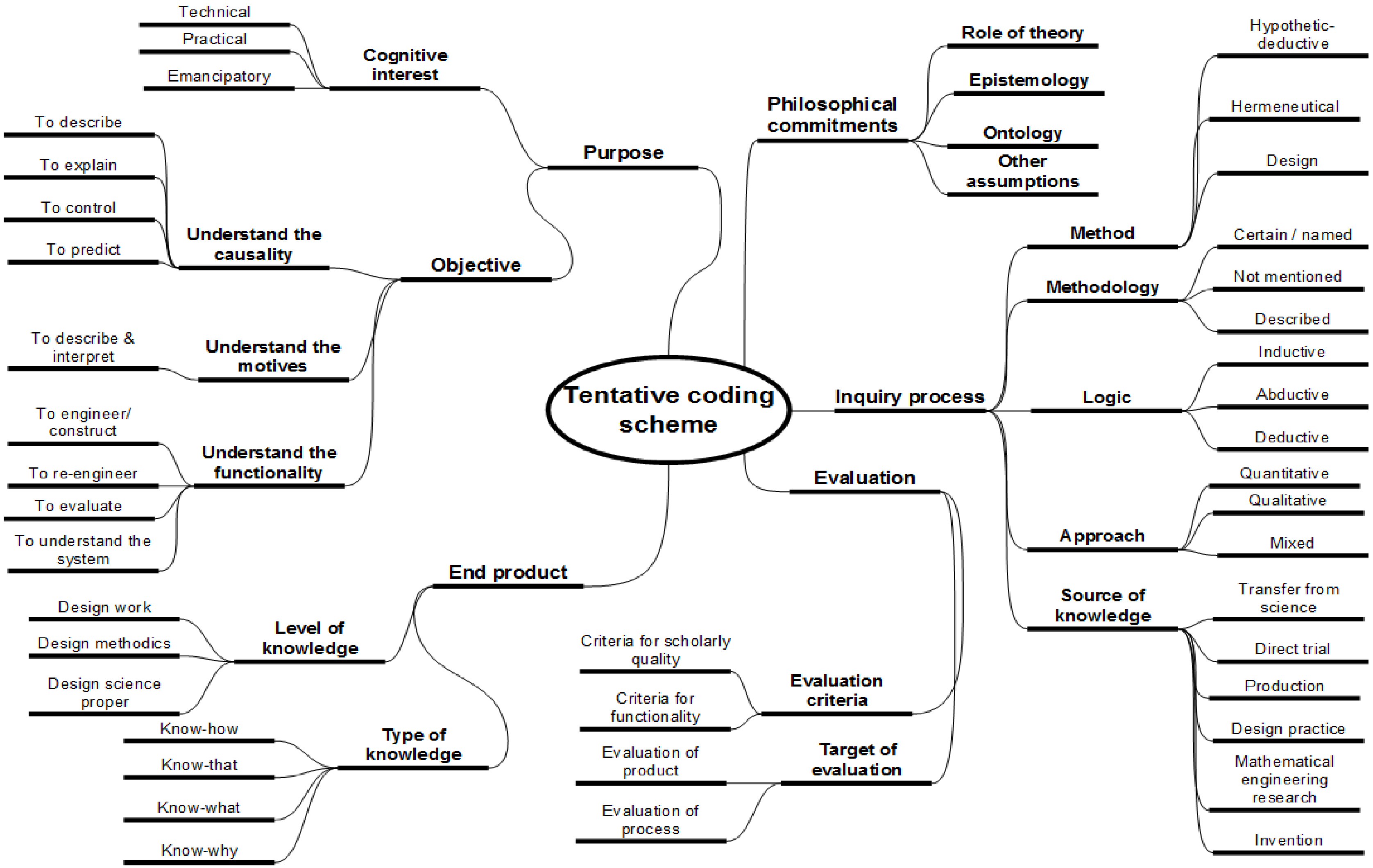


Figure 14. The tentative coding scheme of the dissertations

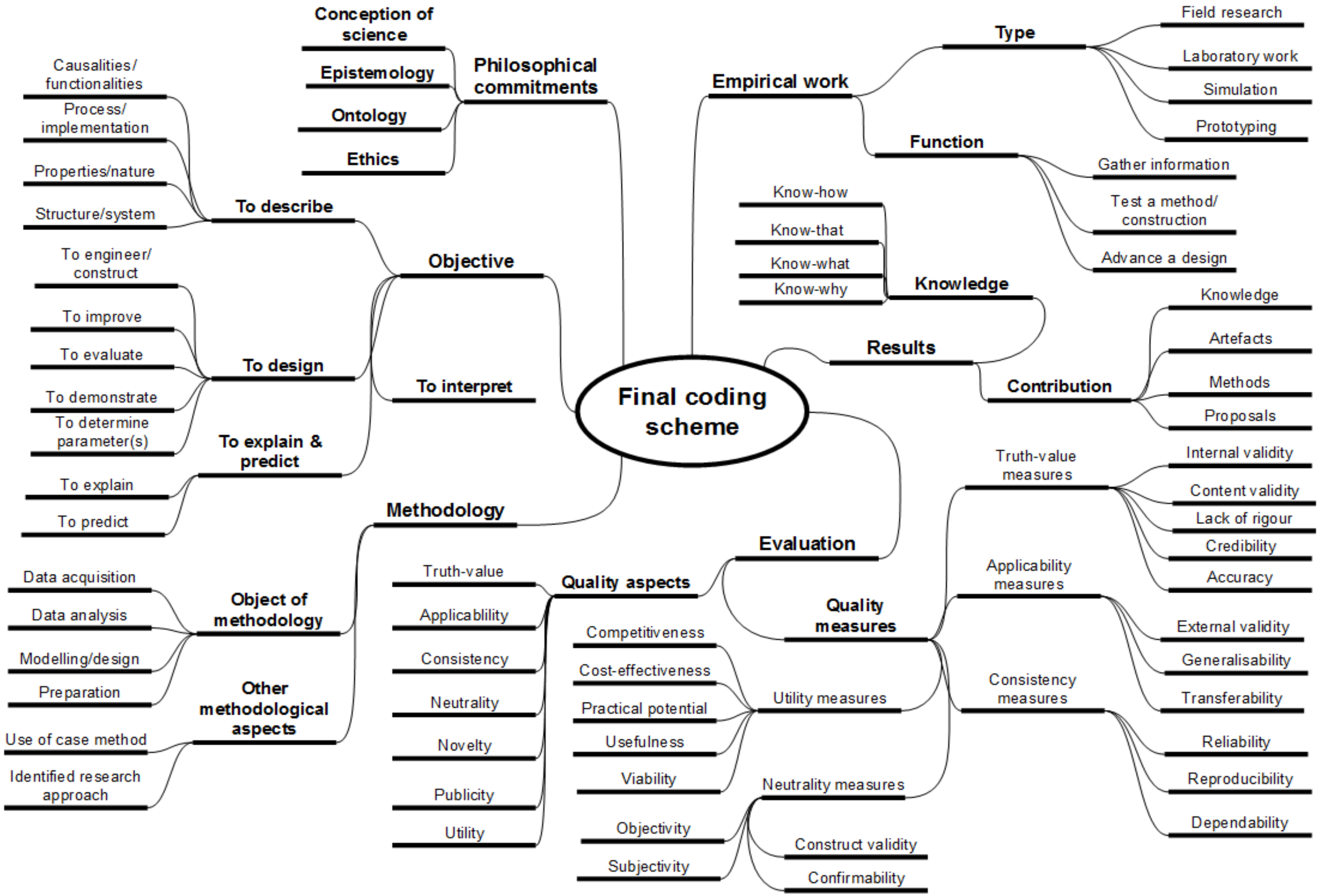


Figure 15. The final coding scheme of the dissertations

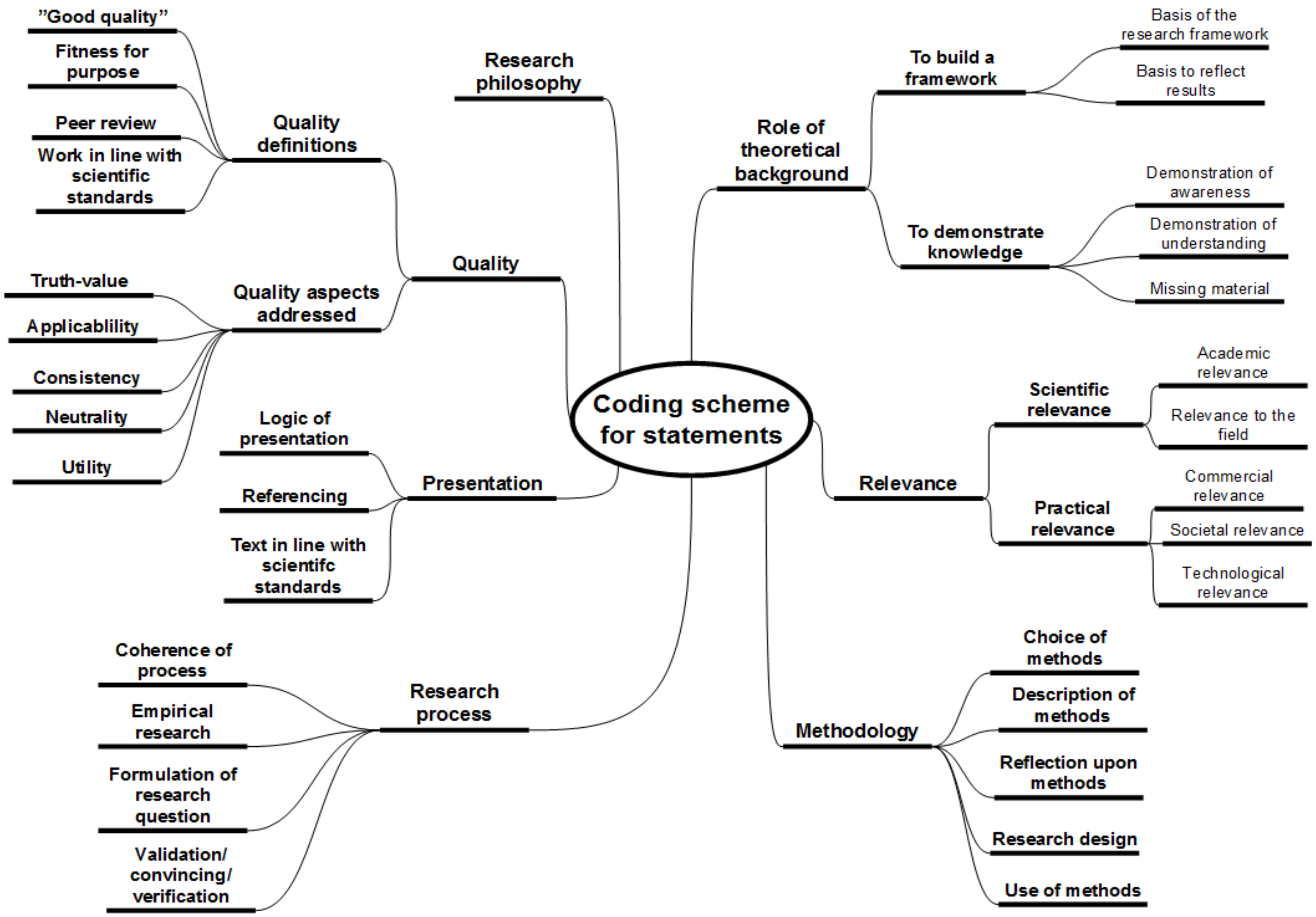


Figure 16. The final coding scheme for the statements

The coding of the statements proceeded along a similar path, but instead of creating a separate tentative coding scheme for the statements, the author used the final coding scheme of the dissertations as the starting point. It soon became apparent that, with the exception of the quality aspects, none of the "branches" of the final coding scheme for the dissertations could be directly applied to the coding of statements. Under the category of quality aspects addressed, novelty was left out of the coding of statements. This was because it was supposed to appear in all the statements, as the examiners had explicitly been instructed to comment upon it. Instead, some of the aspects central to the coding of dissertations were similarly not present in the statements, such as objectives or results.

The statements also contained aspects that were not present in the dissertations, such as comments concerning the written presentation or evaluations regarding the theoretical background included in dissertations. The statements are much smaller documents than the dissertations and thereby contained much less information to be coded. Thus, the coding scheme for the statements evolved considerably. The final coding scheme for the statements is presented in Figure 16. In addition to the coding scheme used for the statements, the quotations containing special criticism or specific appraisal were noted and coded.

Frequency tables were the means most used for displaying the data in the coding phases of both of the data sets. The tables were employed to check the coding of all documents and to evaluate the applicability of the categorisation. In the case of some but not all codes and categories, short memos were written to clarify the logic behind the coding and to ensure maintenance of the same logic throughout the coding of all the data.

6.2.3. Conclusion drawing and verification

Counting the frequencies of codes and categories and exploring their distributions in documents and families of documents also yielded the best tools for conclusion drawing and verification. The overall situation was analysed by viewing the totality of all the dissertations. The preconceived sources of differences (faculty and gender of the doctoral candidate and the form of dissertation) were examined by comparing the patterns of codes in different groups.

Already in the early stages of the analysis, the dissertations seemed to form five clusters which differed from the five faculties. These clusters were named research profiles, and all the documents were appointed one or (in some cases) two applicable profiles. As the coding proceeded and the categories were formed theme by theme, the profiles were also tested by checking the patterns of codes in each profile and observing if all the dissertations in a certain profile followed these patterns. The "outliers" were noted with respect to each theme. In the end, the dissertations not following the patterns of the profiles in each theme were collected. It was noted that many of the misfits were repeated across the themes and were resolved by excluding the dissertation from that particular profile (if the dissertation had originally been appointed two profiles) or by changing the profile of the dissertations. Although some problems still remained, they were typically related to only one of the five themes, and not repeated across the themes. The original five profiles appeared to be justified, and their relevance was evaluated by comparing the explanatory power of clustering according to the profiles with the explanatory power of clustering according to the faculties. This is elaborated upon further in the empirical findings and conclusions sections of this dissertation.

Dissertations were considered to be the primary data in answering the first of the subsidiary research questions “What are the essential features of engineering science?”. The third subsidiary research question “What sort of challenges does engineering science pose for junior researchers?” was hoped to be understood mainly through the analysis of the statements. Answering the second subsidiary question “What kind of philosophy of science does engineering science entail?” was suspected to require a reciprocal analysis of both sets of data.

In drawing final conclusions, the empirical findings and the answers to the research questions that those suggest are reflected upon in view of the literature.

6.3. Summary

This chapter has described the processes of data gathering and analysis. The collection of data began with the choice of dissertations. A preliminary study done by the author in the summer of 2007 suggested that a study of fifty dissertations would be a sufficient and sensible extent of data resource-wise. Dissertations were chosen from the DPub electronic database, as it provided easier access to the data, which could then be analysed with the help of suitable qualitative research software.

The desire to understand the current state of affairs meant that the dissertations included in the selection were required to be relatively recent. Thus, the author decided to make the selection based on the database content from the beginning of September 2011 and to choose dissertations that were as new as possible. The gender distribution was analysed in order to avoid any heavy over- or underrepresentation which might interfere with the interpretation process. Also, the distribution between compilations and monographs was similarly checked. The distribution of dissertations from different faculties was designed to give a fairly representative picture but also to ensure a comprehensive understanding.

The selection of the dissertations simultaneously defined the selection of the statements. The demography of the people behind the statements was analysed against the type and nationality of their home institutions.

Data were coded according to the principles of theory-directed coding in two stages (dissertations first and statements second). Counting the frequencies of codes and categories and exploring the distributions of those in documents and families of documents proved to be the most useful aids in both the reduction of data and drawing of conclusions. According to the principles of theory-directed coding, the reduction of the data began with the creation of a tentative coding scheme based on the literature. As the coding of the dissertations proceeded, the coding scheme changed. Some changes were due to the things which emerged from the data, some changes were due to the fact that the categorisations included in the tentative scheme gained no empirical support, and some changes arose from the literature, as the ideas emerging from the data concurrently led to the inclusion of new additional viewpoints in the theoretical overview of the phenomenon.

In practice, the coding of dissertations was executed in six rounds. Depending on the theme, the coding varied from a rather straightforward application of the categories of the coding scheme to a virtually grounding of the coding in the data. In the areas which underwent significant changes to the coding scheme, all the applicable quotations were first marked with one code and compiled into a new document, which was then worked through numerous times until satisfactory categories and codes were arrived at.

Counting the frequencies of codes and categories and exploring their distributions in documents and families of documents were the tools also employed in the processes of conclusion drawing and verification. The preconceived sources of differences (faculty and gender of the doctoral candidate and the form of dissertation) were examined by comparing the patterns of codes in different groups.

From the early stages of the analysis, the dissertations seemed to form five clusters which differed from the five faculties. These clusters were named research profiles, and all the documents were appointed one or two applicable profiles. The profiles were tested by checking the patterns of codes in each profile and by seeing if all the dissertations in a certain profile followed these patterns.

The next chapter will show what the processes described above yielded and will introduce the results of the data collection and analysis. The processes of describing the data and interpreting of it are intentionally separated into different chapters. Thus, the actual conclusions will be drawn in Chapter Nine.

7. Description of the reduced data

> *Before explanation can begin, its object—the explanandum—must be described. Any description may be said to tell us what something "is." (von Wright 1971, 135)*

Miles and Huberman (1994, 10-12) describe data reduction processes as processes that sort and organise data to enable the drawing and verification of conclusions. The purpose of this chapter is to display the reduced data from the research to the reader. Although the coding process unavoidably entails some interpretations from the researcher, the processes of describing the data and explaining the studied phenomena are intentionally separated into different chapters so that the reader may follow the analysis step by step and be able to draw conclusions that may differ from those of the researcher.

Many of the results presented in the different tables are recorded as percentages. This form of tabulation is not intended to serve as a quantitative or statistical analysis, as the study is qualitative and hermeneutic in nature. It is done in order for the reader (as well as the researcher) to be more readily able to observe the similarities and differences and grasp the qualitative trends in the different sets of data. These observations form the basis for seeing the phenomenon behind the individual instances and for enabling an understanding of the whole picture.

7.1. General features of the research presented in the dissertations

The pages which follow present the central features of engineering science research as presented in the data of the 50 doctoral dissertations under study. The appearance of different features in the entirety of the data is collectively presented in Table 14. The following sections introduce the different aspects of engineering science in more detail.

7.1.1. Philosophical considerations

Instances of philosophical considerations were relatively rare in the data. More than two-thirds of the dissertations (34) contained no reference to any kind of philosophical questions related to the inquiry process, knowledge, the world or ethics.

Approximately one-quarter of the dissertations (12) entailed an explicit conception of science to some extent. In some dissertations, this was expressed as a commitment to a particular form of scientific inquiry such as positivism, hermeneutics or design science. In others, it was more of a free description of the underlying thoughts and assumptions guiding the research process.

Table 14. Features of engineering science in the dissertations at TUT

		Appearance in all dissertations
Philosophical commitments		
	Conception of science	24 %
	Epistemology	14 %
	Ontology	10 %
	Ethics	2 %
	Not mentioned	68 %
Research objectives		
	To describe	42 %
	To design	86 %
	To explain	22 %
	To interpret	12 %
Function of empirical work		
	To advance a design	32 %
	To create knowledge	52 %
	To test a construction	42 %
Form/type of empirical work		
	Field research	42 %
	Laboratory work	34 %
	Prototyping	10 %
	Simulation	30 %
Methodology		
	Data acquisition	72 %
	Data analysis	74 %
	Modelling / design	56 %
	Preparation	18 %
	Case method	28 %
	Research approach	28 %
Type of resulting knowledge		
	Know-how	66 %
	Know-that	60 %
	Know-what	6 %
	Know-why	14 %
Explicated contribution		
	Artefact	28 %
	Knowledge	38 %
	Method	42 %
	Proposal	12 %
	Not named	46 %
Quality aspects addressed		
	Truth-value	44 %
	Applicability	40 %
	Consistency	44 %
	Neutrality	12 %
	Novelty	16 %
	Publicity	2 %
	Utility	70 %
	Nothing	8 %
Quality measures used		
	Measures of truth-value	22 %
	Measures of applicability	24 %
	Measures of consistency	28 %
	Measures of Neutrality	14 %
	Measures of Utility	54 %
	Nothing	28 %

Epistemological, ontological and ethical considerations were coded when these terms were referenced. About one in seven dissertations (7) included some epistemological remarks, and every tenth dissertation (5) contained some ontological remarks. Research ethics were discussed in one dissertation.

7.1.2. Objectives of the research

Objectives of the dissertations formed four main categories: to describe, to design, to explain and to interpret. Most dissertations had several objectives which related to more than one category. In 21 dissertations, one of the objectives was to describe something, but in just one dissertation, this was the only objective. The objective formed four further subcategories related to the target of the description: to describe causalities/functionalities, to describe process/implementation, to describe properties/nature and to describe structure/system. Usually, the objective of describing something acted as a prerequisite for reaching the other objectives of the inquiry process.

Most of the dissertations aimed at designing something. The objective “to design” included such verbs as to engineer/construct, to evaluate, to improve, to demonstrate and to determine parameters. Forty-three out of 50 dissertations had these design-oriented objectives, with 33 dissertations aiming at constructing something, 17 dissertations at evaluating something, 13 dissertations at improving something and ten dissertations at demonstrating something.

Explaining the interrelations or causalities was stated as an objective in 11 dissertations. Three dissertations also aimed to predict something. This formulation of objectives was the closest to the typical objectives of the positivistic natural science research. However, in most cases, it was accompanied by design-oriented objectives.

Finally, six dissertations contained the objective of interpreting. Some of them had hermeneutical understanding as the only objective besides describing, but in one case, this was complemented by design objectives, and in another case, by explanation objectives.

7.1.3. The nature of the empirical work

The empirical work conducted and reported in the dissertations differed in both form (discussed in the next paragraph) and function (discussed here). In 26 dissertations, the function of the empirical work was to gather information for analysis and thus to create knowledge. In 21 of them, the empirical work was done in order to test a method or construction. In 16 of them, it was done to advance a design. Advancing a design appeared as an iterative process, where the final design was sought by trying out various options and altering the design according to the outcomes. Therefore, this third empirical approach of advancing a design was markedly different from the first two. Again, some of the dissertations contained more than one function for the empirical work, but none of them served all three different functions.

The form of the empirical work consisted of four categories. Twenty-one dissertations included field work; i.e., data acquired in real settings such as companies or measurements made in natural environments. Seventeen dissertations presented laboratory work, 15 entailed empirical work performed by computers and mathematical simulations, and in five dissertations, the empirical work took the form of the building of a real prototype of some kind. The term *prototyping* is used broadly in this context to include any kind of testing based on real constructions explicitly built for testing purposes. It also includes piloting, for example. This “building for testing purposes” is also the element that distinguishes prototyping from field work. The difference between prototyping and laboratory work is that a prototype represents a construction, whereas a laboratory test represents a certain feature or phenomenon.

7.1.4. The methodology used in the dissertations

The methodology used and described in the dissertations served four main purposes: data acquisition, data analysis, modelling and design, and preparation. In 36 doctoral theses, the methodology included a description of the methods used for collecting the data to be analysed. In 37 dissertations, there was a description of the methods used for analysing the data. In 28 dissertations, the methodology consisted of a description of the methods used for modelling or designing a construction. In nine dissertations, methods used for preparations before the actual laboratory experiments or other forms of data acquisition were described.

Generally, the methodology was described in a practical manner as the actual methods chosen and used for the purposes mentioned above. A more philosophical discussion about the methodology, which was realised in the description of the adopted research approach, was presented in only 14 dissertations. These discussions included, for example, argumentations on whether to adopt a qualitative or quantitative approach and on positioning one’s research in the normative vs. descriptive and theoretical vs. practical dimensions.

Pertaining to the basic methodological descriptions, in 14 dissertations, the use of terms *case method* or *case studies* appeared. However, it was impossible to distinguish a single interpretation of the terms, as they were used in so many different ways. Case study was referred to as a research approach, data collection method and/or data analysis method, but was also used with no explanation of what it was methodologically considered to be. This eclectic use of case terminology illustrates rather well the general approach to methodology: the methods are described but not truly discussed.

7.1.5. Research outcomes

The outcomes of the research appeared in the dissertations in a twofold manner. On the one hand, there were outcomes that were explicitly presented as the contributions of the research. On the other hand, there was the knowledge that had been created through scientific inquiry and described in the results, conclusions and discussions of the dissertations (referred to herein as results). Thus, every dissertation contained results, but the contributions as research outcomes with added value in certain contexts were presented in just 26 dissertations.

The resulting knowledge seemed to be of four types. The most common type of knowledge concerned the way in which different technical aspects could or should be done, and was deemed know-how. Know-how was created in two-thirds of all the dissertations. Knowledge stating how certain things are was called know-that, and was produced in nearly as many dissertations. Know-that is the basic form of declarative knowledge often expressed also in the form of laws, theories or equations. A considerably smaller amount of the dissertations contained new knowledge about human relations with technology. These included matters such as insights into the user experiences of technologies, customer expectations of technological solutions and application of technologies in societal and cultural contexts. This form of knowledge was named know-why. The fourth type of knowledge dealt with the essence of technological constructs and the structural rules of systems. This type was labelled know-what, and it was produced in three dissertations.

The four knowledge types were originally suggested by the summary of the literature on typologies on engineering knowledge (see Table 4). They turned out to be present in the data also, but sometimes it was difficult to distinguish between know-how and know-that knowledge, as it seemed that the same issue could be expressed in both ways. This was most evident in the cases where the dissertation contained the conclusion that something could be done in a certain way or that something enabled a certain thing. These conclusions entail the know-how knowledge feature that something can be done, but they did not state that it should be done, nor did they indicate what exactly would be achieved by doing the demonstrated thing. The expression pertained to the know-that type (a conclusion that something can be done), but the discovery was not of a general nature akin to laws or theories, but was rather knowledge about a particular situation.

In a little over half of the dissertations, the contributions of the research were explicitly named. Most commonly, the contribution was stated to be “a method” or “knowledge.” Methods included methods for analysis, design, implementation and evaluation. Knowledge usually referred to explicit or conceptual know-that type of knowledge or findings. This included elements such as analysis, specifications, evaluation and understanding. In one-quarter of the dissertations, the contribution was explicated as an artefact, and in six dissertations a proposal. Artefacts could either be material, such as materials and physical tools or machines, immaterial like algorithms, or a combination of both. Proposals were recommendations relating to methods, artefacts or knowledge. Thus, the difference between those and the three other types of contributions was semantic rather than epistemological. In addition, these contributions were sometimes described as models or frameworks. The use of those two terms, however, was diverse, and sometimes they appeared to refer to method-like outcomes, sometimes to conceptual knowledge and sometimes even to the artefact-like outcomes of the research. Also, it was typical for a dissertation to include several different kinds of contributions. In fact, one dissertation even suggested that it contributed to all four areas (artefact, knowledge, method and proposal).

7.1.6. Evaluation and quality issues

The evaluation of the quality of the inquiry process and the results seemed to take place at two levels, general and practical. At a general level, certain aspects were discussed as they were perceived to be related to the quality of the research; yet, the aspects were not necessarily operationalised into any measures that could have been used to evaluate the quality. At a practical level, thesis authors used different measures of quality in the evaluation and discussion of the quality of their own work. Table 15 sums up the quality measures used in the dissertations.

Table 15. Measures of quality used in the dissertations

		Number of dissertations where used*	Appearance in all dissertations (%)
Measures of truth-value		**11**	**22 %**
	Internal validity	6	12 %
	Content validity	1	2 %
	Accuracy	3	6 %
	Lack of rigour	2	4 %
	Credibility	3	6 %
Measures of applicability		**12**	**24 %**
	External validity	6	12 %
	Generalisability	10	20 %
	Transferability	2	4 %
Measures of consistency		**14**	**28 %**
	Reliability	11	22 %
	Reproducibility	4	8 %
	Dependability	3	6 %
Measures of neutrality		**7**	**14 %**
	Objectivity	1	2 %
	Subjectivity	2	4 %
	Confirmability	3	6 %
	Construct validity	4	8 %
Measures of utility		**27**	**54 %**
	Competitiveness	6	12 %
	Cost-effectiveness	5	10 %
	Practical potential	6	12 %
	Usefulness	8	16 %
	Viability	7	14 %

* As several different measures of the same aspect of quality may be used in one dissertation, the numbers of measures used are not additive.

The aspect of quality discussed most was utility, which was addressed in thirty-five dissertations. The quality aspects more traditionally connected with scientific inquiry—truth-value, applicability and consistency—were somewhat discussed in less than half of the theses, and the aspects of neutrality and novelty were present in fewer than one in six dissertations. The aspect of publicity was addressed in one case. Four dissertations had no references of any kind to the quality of the research.

The most commonly used quality measures were also related to the utility of the research. These measures included competitiveness, cost-effectiveness, practical potential, usefulness and viability, and any or some of these were present in 27 of the dissertations. Measures of consistency (reliability, reproducibility, dependability) were used in 14 dissertations; measures of applicability (external validity, generalisability, transferability) were employed in 12; measures of truth-value (internal validity, content validity, accuracy, lack of rigor, credibility) were found in 11; and measures of neutrality (objectivity, subjectivity, confirmability, construct validity) were present in seven dissertations. Fourteen dissertations contained no attempts whatsoever to employ any measures of research quality.

7.2. Effect of the background variables

In order to elucidate what kinds of differences would surface, general features of engineering science were checked against the background variables of the data, namely the form of the dissertation (compilation vs. monograph) and the gender of the author. In each case, the complete information is presented in a table, and the most notable differences are commented upon in this section.

7.2.1. Monographed versus compilation dissertations

The data consisted of 14 monographs and 36 compilations. The central features of engineering science of these different types of dissertations are presented in Table 16. There were no remarkable differences between the monographs and compilations from the viewpoint of this study. It appeared as though the philosophical considerations, especially the ones related to epistemological questions, were somewhat more common in the monographs, but were still somewhat scarce in both.

As concerns empirical work, the monograph dissertations most often entailed field research, whereas the compilation dissertations included laboratory work. This also explains the most notable difference in the methodological approaches, namely the presence or absence of preparation methods in research. The type of knowledge produced was also slightly different in profile, with monographs producing less know-how and know-that knowledge, but more know-what knowledge compared to the compilations. In fact, there was no know-what knowledge created in the compilation dissertations.

The differences concerning quality aspects and measures were concentrated in the evaluation of the utility of the research and use of utility measures in dissertations.

Although utility aspects were the most commonly addressed quality aspects and utility measures were among the most commonly used quality measures in both dissertation types, it was still more common to discuss the utility of the research in compilations. Utility as a quality aspect was addressed in virtually every monograph, and utility measures were utilised in two-thirds of them.

7.2.2. Gender-related differences in the dissertations

The differences between the dissertations written by women or by men were quite similar to the differences between the monograph and compilation dissertations. A summary of all aspects is presented in Table 17.

The research objectives of women more often related to explanations and to the function of empirical work in creating knowledge than did the research objectives of men. Women also did laboratory work relatively more frequently but did fewer simulations than men. Probably owing to this higher share of lab work, women also employed more preparation methods but fewer modelling methods did than men did. Even though women seemed to lean more towards a traditional-experimental science direction, it is worth noting that more than three quarters of them also employed design-oriented objectives in their work.

Table 16. Features of engineering science in monograph and compilation dissertations

		Monographs (N=14)	**Compilations (N=36)**
Philosophical commitments			
	Conception of science	29 %	22 %
	Epistemology	29 %	8 %
	Ontology	14 %	8 %
	Ethics	7 %	0 %
	Not mentioned	50 %	75 %
Research objectives			
	To describe	57 %	39 %
	To design	86 %	89 %
	To explain	14 %	28 %
	To interpret	21 %	11 %
Function of empirical work			
	To advance a design	29 %	33 %
	To create knowledge	57 %	50 %
	To test a construction	43 %	42 %
Form/type of empirical work			
	Field research	57 %	36 %
	Laboratory work	14 %	42 %
	Prototyping	14 %	8 %
	Simulation	21 %	33 %
Methodology			
	Data acquisition	79 %	69 %
	Data analysis	86 %	69 %
	Modelling / design	43 %	61 %
	Preparation	0 %	25 %
	Case method	43 %	32 %
	Research approach	36 %	25 %
Type of resulting knowledge			
	Know-how	50 %	72 %
	Know-that	43 %	67 %
	Know-what	21 %	0 %
	Know-why	14 %	14 %
Explicated contribution			
	Artefact	21 %	31 %
	Knowledge	43 %	36 %
	Method	50 %	39 %
	Proposal	21 %	8 %
	Not named	36 %	50 %
Quality aspects addressed			
	Truth-value	43 %	39 %
	Applicability	43 %	44 %
	Consistency	7 %	14 %
	Neutrality	0 %	22 %
	Novelty	7 %	0 %
	Publicity	50 %	42 %
	Utility	93 %	69 %
	Nothing	0 %	11 %
Quality measures used			
	Measures of truth-value	21 %	31 %
	Measures of applicability	7 %	19 %
	Measures of consistency	29 %	19 %
	Measures of neutrality	36 %	31 %
	Measures of utility	64 %	33 %
	Nothing	14 %	33 %

Table 17. Features of engineering science in male- and female-authored dissertations

		Male (N=32)	Female (N=18)
Philosophical commitments			
	Conception of science	25 %	22 %
	Epistemology	13 %	17 %
	Ontology	6 %	17 %
	Ethics	3 %	0 %
	Not mentioned	66 %	72 %
Research objectives			
	To describe	38 %	50 %
	To design	91 %	78 %
	To explain	13 %	39 %
	To interpret	6 %	22 %
Function of empirical work			
	To advance a design	34 %	28 %
	To create knowledge	38 %	78 %
	To test a construction	47 %	33 %
Form/type of empirical work			
	Field research	47 %	33 %
	Laboratory work	25 %	50 %
	Prototyping	13 %	6 %
	Simulation	38 %	17 %
Methodology			
	Data acquisition	69 %	78 %
	Data analysis	69 %	83 %
	Modelling / design	66 %	39 %
	Preparation	6 %	39 %
	Case method	25 %	33 %
	Research approach	25 %	33 %
Type of resulting knowledge			
	Know-how	69 %	61 %
	Know-that	59 %	61 %
	Know-what	6 %	6 %
	Know-why	9 %	22 %
Explicated contribution			
	Artefact	34 %	17 %
	Knowledge	38 %	39 %
	Method	44 %	39 %
	Proposal	13 %	11 %
	Not named	41 %	56 %
Quality aspects addressed			
	Truth-value	44 %	33 %
	Applicability	41 %	50 %
	Consistency	9 %	17 %
	Neutrality	19 %	11 %
	Novelty	3 %	0 %
	Publicity	44 %	44 %
	Utility	75 %	61 %
	Nothing	9 %	6 %
Quality measures used			
	Measures of truth-value	28 %	28 %
	Measures of applicability	9 %	28 %
	Measures of consistency	22 %	22 %
	Measures of Neutrality	25 %	44 %
	Measures of Utility	38 %	50 %
	Nothing	28 %	28 %

7.3. The five distinct research profiles

The analysis followed the principles of theory-guided coding, which allowed one to take into account issues arising from the data. Already in early stages of the analysis, an impression of five distinct research profiles emerged and continued to strengthen throughout the analysis. Some of the dissertations exchanged places among the profiles during the coding processes, but the original idea of the profiles remained virtually unchanged and became theoretically saturated, as all the dissertations could be assigned to one or two profiles.

In the beginning, several dissertations were situated within two profiles, but as the analysis proceeded, some fully shifted to one profile or the other. A few dissertations also shifted from one profile to another. In the end, there were 35 dissertations belonging to only one profile and 15 dissertations situated in two profiles. This type of "shared" dissertation existed in all faculties and all profiles.

The profiles were named Experimental design science (EDS), Mathematical design science (MDS), Naturalistic design science (NDS), Explorative inquiry (EI) and Interpretive inquiry (II). The names mainly reflect the research objectives and type of empirical work prevailing in each profile. The EDS profile held the most theses and NDS the second most, with 21 and 20 dissertations, respectively. The MDS profile included 12 dissertations, the II profile contained 7 and the EI profile had 5.

The general features of the research profiles are presented in Table 18. Each profile is then discussed in relation to the other profiles and to the general features of the whole data.

Table 18. Features of engineering science in dissertations falling into different research profiles

		EDS (N=21)	**MDS (N=12)**	**NDS (N=20)**	**EI (N=5)**	**II (N=7)**
Philosophical commitments						
	Conception of science	5 %	0 %	45 %	20 %	57 %
	Epistemology	0 %	0 %	20 %	0 %	71 %
	Ontology	0 %	0 %	15 %	0 %	57 %
	Ethics	0 %	0 %	0 %	20 %	0 %
	Not mentioned	95 %	100 %	45 %	80 %	0 %
Research objectives						
	To describe	33 %	17 %	50 %	40 %	86 %
	To design	100 %	92 %	90 %	100 %	29 %
	To explain	24 %	25 %	10 %	80 %	14 %
	To interpret	0 %	0 %	10 %	0 %	86 %
Function of empirical work						
	To advance a design	48 %	42 %	35 %	20 %	0 %
	To create knowledge	57 %	17 %	45 %	100 %	100 %
	To test a construction	33 %	67 %	55 %	20 %	0 %
Form/type of empirical work						
	Field research	10 %	33 %	70 %	20 %	100 %
	Laboratory work	76 %	17 %	5 %	80 %	0 %
	Prototyping	19 %	8 %	10 %	0 %	0 %
	Simulation	24 %	83 %	25 %	0 %	0 %
Methodology						
	Data acquisition	90 %	33 %	70 %	80 %	100 %
	Data analysis	86 %	50 %	70 %	80 %	100 %
	Modelling / design	52 %	100 %	55 %	20 %	14 %
	Preparation	43 %	8 %	0 %	40 %	0 %
	Case method	5 %	8 %	50 %	0 %	86 %
	Research approach	10 %	8 %	45 %	20 %	86 %
Type of resulting knowledge						
	Know-how	76 %	67 %	70 %	40 %	29 %
	Know-that	67 %	75 %	45 %	100 %	43 %
	Know-what	0 %	8 %	10 %	0 %	0 %
	Know-why	0 %	8 %	20 %	0 %	86 %
Explicated contribution						
	Artefact	24 %	42 %	30 %	0 %	0 %
	Knowledge	33 %	25 %	40 %	40 %	86 %
	Method	29 %	42 %	50 %	40 %	57 %
	Proposal	10 %	17 %	10 %	20 %	29 %
	Not named	62 %	58 %	35 %	60 %	14 %
Quality aspects addressed						
	Truth-value	24 %	33 %	60 %	40 %	100 %
	Applicability	24 %	42 %	50 %	20 %	86 %
	Consistency	29 %	42 %	45 %	60 %	100 %
	Neutrality	0 %	8 %	20 %	0 %	43 %
	Novelty	14 %	25 %	20 %	0 %	0 %
	Publicity	0 %	0 %	5 %	0 %	14 %
	Utility	62 %	83 %	90 %	20 %	57 %
	Nothing	14 %	0 %	0 %	40 %	0 %
Quality measures used						
	Measures of truth-value	5 %	17 %	25 %	20 %	71 %
	Measures of applicability	10 %	8 %	35 %	20 %	86 %
	Measures of consistency	10 %	8 %	30 %	20 %	86 %
	Measures of neutrality	0 %	0 %	20 %	0 %	71 %
	Measures of utility	48 %	75 %	70 %	0 %	43 %
	Nothing	48 %	25 %	15 %	80 %	0 %

7.3.1. Experimental design science

Dissertations fitting the experimental design science profile contained a strong design orientation. In all of the EDS dissertations, to design was stated as one of the research objectives. Some dissertations also included objectives of describing and/or explaining certain matters. The form of the empirical work conducted was predominantly experimental, with laboratory work conducted in three out of four dissertations and clearly being the dominant type of empirical work. Simulation, prototyping and field work were incorporated to a much lesser extent.

The empirical work was used most of the time to create knowledge; in a little under half of the theses it was used to advance a design, and in about third of the theses to test a construction. The methods used were in line with the functions of empirical work, as methods of data acquisition and analysis were emphasised. Preparation methodology and modelling/design methods were also strongly present in the EDS dissertations. The research approach was usually undefined, and the philosophical aspects of research were discussed in only one of the 21 dissertations. The results of the research contained know-how and know-that knowledge virtually equally. The contributions were not often explicitly stated, but knowledge and methods were the most commonly named ones.

Utility was definitely the quality aspect most addressed and utility measures were the quality measures most used. However, almost half of the dissertations included no quality measures. Truth-value, applicability and consistency issues were each discussed in approximately one-quarter of the dissertations, and some measures for applicability and consistency were used in ten percent of them.

7.3.2. Mathematical design science

Dissertations falling in the profile category of mathematical design science also had a strong design orientation, with eleven out of twelve theses having an objective to design, and all of the dissertations using modelling or design methodology. The objectives of the dissertations were similar in nature to those of EDS dissertations. As in EDS dissertations, philosophical issues were not discussed.

In MDS theses, the dominant function of empirical work was to test a construction. In addition, advancing the design was commonly described as the function of empirical work, but the creation of knowledge only rarely. Methods of data acquisition were described in about one-third of the dissertations and methods of data analysis in one half. The empirical work conducted was usually of the simulation type.

Like in the EDS dissertations, the resulting knowledge in MDS dissertations was typically characterised as know-that or know-how. In the EDS dissertations, the know-how was slightly more common than know-that, and in MDS dissertations, the opposite was true. In more than half of the dissertations, the contributions were not explicated, but when they were, the most common types of contributions were artefacts and methods.

Utility was again the aspect of quality most addressed and most measured. Three-quarters of the dissertations included some measures of utility. Other quality measures were not really applied. After utility, the most discussed quality issues were applicability and consistency, but those were not operationalised with measures.

7.3.3. Naturalistic design science

The dissertations falling under the naturalistic design science profile comprised the third group representing design science. In these theses, the design-oriented objectives were mainly accompanied by the objective to describe. The objectives to explain and to interpret were each present in ten percent of the dissertations.

Contrary to the cases of EDS and MDS, more than half of the NDS dissertations addressed some philosophical issues, and nearly half of them possessed a defined conception of science. Also, nearly half of the dissertations followed a named research approach.

The empirical work in NDS dissertations was strongly inclined towards field research, hence the origin of the term *naturalistic*. However, concerning the function of the empirical work, there was no strong inclination in one direction; that is, all three different functions were present among the dissertations in a balanced manner. The methodology was concentrated in the data acquisition and analysis portion, and half of the dissertations cited the case method as having some kind of role. However, more than half of the dissertations also used modelling/design methods.

The resulting knowledge in NDS dissertations was usually know-how. Among the results, know-that knowledge played a smaller role in NDS than in EDS or MDS. Know-what knowledge was produced in ten percent of the dissertations and know-why knowledge in 20 percent. Methods were cited as the contributions of the dissertation in half of the cases.

Similarly to EDS and MDS, the role of utility among the quality aspects is strong. Eighteen out of 20 dissertations included some discussion about quality, and in 14 dissertations, some utility measures were used. Truth-value was the second-most-discussed quality aspect, but measures of applicability were the second-most-applied quality measures.

7.3.4. Explanatory inquiry

Dissertations in the profile category of explanatory inquiry also entailed a strong design orientation in the sense that every single one of them named design-oriented objectives. They did not, however, usually employ modelling/design methods. Along with the objective of designing something, almost all of the EI works aimed at explaining, and some also aimed at describing. They strongly included laboratory-based empirical work serving the function of creating knowledge and also included methods used for data acquisition, analysis and preparation. Thus, despite the stated objective to design, the EI dissertations convey more an image of positivistic and natural science than of design science.

All of the EI dissertations produced the know-that knowledge type. Some of the dissertations also produced the know-how knowledge type, but none of them produced know-what or know-why knowledge types. Contributions of the research were more often unnamed than named, and no artefacts were named as contributions.

Philosophical aspects of the research were not touched upon in four out of five dissertations. Similarly, four out of five dissertations did not employ any measures for research quality. The most commonly addressed quality aspect was not utility but rather consistency, which was discussed in three dissertations. Truth-value was addressed in two dissertations, and applicability and utility in one dissertation each.

7.3.5. Interpretive inquiry

Interpretive inquiry differed from all the other profiles with respect to objectives. The objectives of II dissertations were primarily to describe and to interpret. The function of the empirical work was solely to create knowledge, and all the empirical work took the form of field research. All the dissertations used methods for data acquisition and analysis, and all but one used case method in some format.

The research approach was described in all but one dissertation, and all of the dissertations included philosophical considerations. The conception of science was explicated in more than half of the dissertations. Epistemological issues were discussed in five out of seven dissertations, and ontological issues in four out of seven.

The resulting knowledge was in most cases of the know-why type. Know-that and know-how knowledge were also produced. Contributions were explicated in six out of seven cases, with knowledge being the most common contribution, and method the next common one. No artefacts were mentioned as contributions.

All of the II dissertations discussed some aspects of quality and employed some measures of quality. As in the case of EI, utility was not the dominant viewpoint of the quality measures; the aspects of truth-value, consistency and applicability were discussed more often. Of the seven dissertations, quality measures relating to applicability and consistency were used in six, and measures for truth-value and neutrality in five.

7.4. Features of research addressed in the statements

The second part of the empirical data consisted of the pre-examiners’ and opponents’ statements from each of the fifty dissertations. Although the statements serve a different function, from the point of view of this study, they are expected to address the same issues. This was also the case in practice. The appearance of the topics of the coding scheme of both statement types is presented in Table 19, and it is apparent that at a general level, they truly do follow the same patterns. Therefore, in spite of the separate coding process, it was decided that all the statements would be analysed as one set of data. It was hoped that this would prevent the analysis from fragmenting into too small of pieces, which could then hinder the formation of the big picture.

Table 19. The presence of different topics in pre-examiners' and opponents' statements

	Research philosophy	Role of theoretical background	Relevance	Methodology	Research process	Presentation	Quality definitions	Addressed quality aspects
Pre-examiners' statements	4 %	58 %	70 %	62 %	65 %	64 %	59 %	43 %
Opponents' statements	12 %	52 %	76 %	54 %	68 %	54 %	60 %	40 %
All statements	7 %	56 %	72 %	59 %	66 %	60 %	59 %	42 %

The dissertations showed only minor differences when checked against the background variables of dissertation type and gender of the author. As there was also no reason to suspect that the examiners would treat the monographs and compilations differently and in many cases were not even aware of the gender of the candidate, the statements were not studied from these viewpoints. However, the dissertations showed quite a lot of variance regarding the faculty of the candidate. It was therefore considered to be important to view the statements from this angle in order to help to understand possible sub-disciplinary cultural differences. These results are presented in section 7.5 along with the other empirical findings regarding the faculties.

Being that the five research profiles emerged from the dissertation data, it was necessary to determine whether they were also supported by the statements. The comparison of statements according to the profile of the dissertation was also hoped to deepen the understanding of the different profiles.

In this section, the findings from the statements are introduced and the different aspects are generally discussed. The issues addressed in the statements are presented in Table 20.

Table 20. Features of engineering science in the statements

	Appearance in all statements (N=149)
Research philosophy	**7 %**
Role of theoretical background	**55 %**
To build a framework	26 %
To demonstrate knowledge	43 %
Relevance	**71 %**
Scientific relevance	54 %
Practical relevance	53 %
Methodology	**58 %**
Choice of methods	30 %
Description of methods	31 %
Reflection upon methods	5 %
Research design	18 %
Use of methods	29 %
Research process	**65 %**
Coherence of process	26 %
Empirical research	30 %
Formulation of the research question	12 %
Validation/convincing/verification	28 %
Presentation	**60 %**
Logic of presentation	43 %
Referencing	15 %
Text in line with scientific standards	15 %
Quality definitions	**58 %**
"Good quality"	9 %
Fitness for purpose	7 %
Peer review	47 %
Work in line with scientific standards	7 %
Quality aspects addressed	**42 %**
Truth-value	13 %
Applicability	17 %
Consistency	17 %
Neutrality	4 %
Utility	13 %

7.4.1. Research philosophy

The comments regarding the philosophical issues of research were even scarcer in the statements than they were in the dissertations. In fact, the comments were so few that it made no sense to try to categorise them into any level of detail.

7.4.2. The role of the theoretical background

The theoretical background and its significance to the research were commented upon in a little over half of the statements. In the minds of the thesis writers, the theoretical background seemingly had two distinct roles or purposes regarding the dissertation work.

Some perceived the role of the theoretical background presented in the dissertation as a demonstration of the doctoral candidate’s knowledge. This view came across in comments regarding the candidate’s awareness of certain earlier research on or understanding of certain issues. Often it was also pointed out that some essential material was missing that should be included in order to show that the candidate was familiar with that material and that the other researchers were given due credit for their work.

Others viewed the theoretical background as the framework essential to guiding the decision-making in different parts of the research process. In this view, the theoretical background was usually 1) criticised or acknowledged for its role in designing research and executing it or 2) acting as the basis for reflecting upon the candidate’s results and contributions. Comments on locating the research gap were also considered here to reflect the kind of thinking that earlier research would form the framework for the dissertation.

Although the aforementioned opinions about the theoretical background of the research are different in nature, they are not exclusive. In fact, many of the examiners presented comments pointing to both views; however, the comments relating to the building of the research framework were considerably fewer than the comments representing the demonstration of knowledge view. All in all, in almost half of the statements, the theoretical background of the dissertation was not evaluated in any way.

7.4.3. Relevance of the research

The relevance of the dissertation research was commented upon in more than two-thirds of the statements. The comments included notions of both scientific and practical relevance—they were each brought up rather evenly in just over half of the statements. Some statements discussed the relevance of the dissertation from both viewpoints.

Scientific relevance was addressed in discussion about the theoretical relevance, relevance to the field or relevance to the academic community. The practical relevance included comments on the technological, commercial and societal significance of the dissertation work and its results. Technological relevance and commercial relevance were each addressed in a little over one-quarter of the statements. Societal relevance was commented upon in about eleven percent of the statements.

7.4.4. Methodology

Remarks regarding methodology included accounts of choice, description of methods, use of methods, research design, and reflection upon the employed methods. A little over half of the statements entailed some methodological notions.

Choice, description and use of methods were each commented upon in about one-third of the statements. First, choice of methods refers to such matters as selection criteria, other options or possibilities, and the justification of choices made. Secondly, description of methods refers to telling the reader what was done and how and to making all phases of the work explicit. Finally, use of methods refers to the employment or execution of the chosen methods and the decisions made regarding the use of certain method or procedure.

Research design was mentioned in a little under one-fifth of the statements. Most of these comments dealt with the storyline or thread combining the studied phenomenon, and used data with the choice and use of methods. Positive remarks were made about the different methods making up a coherent whole, and negative remarks about the missing big picture. The reflection upon methods; e.g., discussing the limitations of the methods used, was addressed in seven statements.

7.4.5. The research process

The research process was discussed in statements from the viewpoint of its general coherence or of attention paid to specific parts of the process such as the empirical work, formulation of research questions or verification of research results. Depending on the dissertation, it was sometimes more understandable to talk about validation or convincingness instead of verification. However, in all these cases, attention was on the procedures made to ensure that the reader could trust the results. Some aspects of the research process were addressed in almost two-thirds of the statements. General coherence, empirical research and validation/convincing/verification were each discussed in a little over one-quarter of the statements, and the formulation of research question was discussed in approximately one in eight statements.

Coherence of the research process is somewhat akin to the research design, but it looks at the research from an angle other than methodological. Sometimes the coherence was just stated in general terms, but other times it was discussed from a particular angle, such as the relationship between the articles and the summary in a compilation dissertation. The coherence of the process was often also described as the logicality of the steps leading from the objective and proceeding through the theoretical and empirical steps to the final conclusions. However, the coherence of work is different from the logic of presentation, as a coherent piece of work can be reported in a disorderly manner.

Aspects related to the empirical part of the dissertation mainly included comments on either the practical experiments or the work done in real life environments such as organisations. Most of the remarks were positive, emphasising either the importance of real experiments as opposed to or to complement simulations, or the challenge in doing research in real life situations as opposed to controlled circumstances.

The formulation of the research question was a specific point discussed only in statements relating to dissertations in which research questions had been presented. No remarks were made about any missing research questions.

7.4.6. Presentation

Presentation was paid attention to in 90 statements. Most of the comments concerned the logic of the presentation, which was addressed in 64 statements. Usually, remarks were made about the readability or ease of following the writer's line of thinking, but sometimes the presentation was further characterised as being textbook-like or too unstructured, for example.

Referencing was brought up in 22 statements. This contained both positive and critical comments and targeted both citing in the text and reference lists. In a similar portion of the statements, the presentation was benchmarked against scientific standards. In most cases, it was stated to have complied with them, but no further elaboration was made on the topic.

7.4.7. Quality of research

Accounts concerning the quality of the dissertation research in statements were versatile. In some statements, the issue of research quality was approached through discussion on aspects such as truth-value, applicability, consistency, neutrality or utility. When coding the statements, the author adopted quality aspects from the coding scheme of the dissertations, with the exception of the aspect of novelty. Novelty was omitted from the quality aspects, as in most faculties the examiners were explicitly asked to comment upon the novelty value of the dissertation. This makes the situation different from that of the other quality aspects.

In the statements, utility was addressed as frequently as truth-value, applicability or consistency. The discussion on neutrality was the rarest. This is different from the dissertations in which utility was clearly discussed more often than the other quality aspects. With novelty excluded, 86 out of 149 statements contained no remarks concerning the quality aspects.

Other approaches taken to evaluate research quality were fourfold: 1) a statement made of good quality, without further elaboration; 2) a "fitness-for-purpose" argument, where quality was perceived through the fulfilment of the research objectives; 3) use of peer review procedures as an indicator of quality; and 4) benchmarking of the work done in the dissertation against scientific standards. Benchmarking was usually done without any further elaboration pertaining to the standards. Of these approaches, peer review indication was the one used most, with nearly half of the statements referring to that. The "good quality," "fitness-for-purpose" and "scientific standard" approaches were used only in a small number of statements. The quality aspect approach to quality was adopted in 63 statements, and any or several of the other indicators in 87 statements. Some statements used both approaches. Thirty-two statements did not make any references to the quality of the dissertation at hand.

7.4.8. Statements of dissertations from different profiles

There were notable, yet not entirely radical differences which emerged regarding the statements related to the dissertations categorised according to the different research profiles. All the findings are presented in detail in Table 21.

Table 21. Features of engineering science in statements regarding dissertations falling into different research profiles

	EDS	MDS	NDS	EI	II
Research philosophy	**2 %**	**0 %**	**10 %**	**7 %**	**20 %**
Role of theoretical background	**49 %**	**42 %**	**58 %**	**73 %**	**75 %**
To build a framework	6 %	11 %	37 %	33 %	65 %
To demonstrate knowledge	46 %	36 %	42 %	67 %	35 %
Relevance	**68 %**	**81 %**	**68 %**	**47 %**	**75 %**
Scientific relevance	46 %	69 %	49 %	40 %	65 %
Practical relevance	56 %	56 %	49 %	27 %	50 %
Methodology	**51 %**	**47 %**	**68 %**	**80 %**	**85 %**
Choice of methods	22 %	25 %	32 %	53 %	50 %
Description of methods	33 %	14 %	34 %	53 %	35 %
Reflection upon methods	3 %	3 %	7 %	7 %	10 %
Research design	8 %	14 %	20 %	20 %	40 %
Use of methods	17 %	19 %	27 %	40 %	75 %
Research process	**76 %**	**47 %**	**69 %**	**60 %**	**75 %**
Coherence of process	25 %	19 %	29 %	27 %	35 %
Empirical research	48 %	14 %	27 %	27 %	20 %
Formulation of research question	5 %	11 %	14 %	7 %	50 %
Validation/convincing/verification	25 %	25 %	32 %	27 %	30 %
Presentation	**54 %**	**64 %**	**66 %**	**60 %**	**60 %**
Logic of presentation	35 %	39 %	49 %	33 %	50 %
Referencing	17 %	28 %	19 %	7 %	15 %
Text in line with scientific standards	13 %	17 %	17 %	20 %	5 %
Quality definitions	**65 %**	**69 %**	**53 %**	**73 %**	**40 %**
"Good quality"	10 %	14 %	7 %	13 %	0 %
Fitness for purpose	6 %	3 %	8 %	20 %	0 %
Peer review	52 %	61 %	41 %	47 %	30 %
Work in line with scientific standards	5 %	3 %	7 %	20 %	20 %
Quality aspects addressed	**33 %**	**36 %**	**41 %**	**47 %**	**60 %**
Truth-value	8 %	3 %	17 %	7 %	25 %
Applicability	11 %	11 %	22 %	13 %	30 %
Consistency	6 %	8 %	15 %	20 %	45 %
Neutrality	2 %	0 %	7 %	0 %	15 %
Utility	17 %	17 %	12 %	13 %	0 %

The presence of comments concerning the research philosophy was not as strongly grouped as in the case of faculties. However, the few philosophical notations were clustered on the one hand in the naturalistic or field-oriented profiles of Naturalistic design science (NDS) and Interpretive inquiry (II); and on the other hand, they were assembled on the research-oriented profiles of II and Exploratory inquiry (EI). There were no research philosophy-related comments among the Mathematical design science (MDS)-profile statements, and hardly any among the Experimental design science (EDS)-profile statements. This is well in line with the existence of philosophical considerations in the dissertations categorised under the different profiles.

Issues related to the theoretical background were addressed more often in the inquiry profiles than in the design profiles. However, the perception of the role of the theoretical background followed a different path. In the statements from profiles of EDS, MDS and EI, the role of background knowledge was more often perceived as the demonstration of candidate’s knowledge, whereas in the statements from the II profile, it was considered to function more as a framework for the research. In the statements from NDS, both views were represented rather equally.

Relevance was discussed the most in MDS-profile statements and the least in EI-profile statements. Again in NDS-profile statements, the scientific and practical relevances of the dissertations were addressed equally. In the EDS-profile statements, the emphasis was on practical relevance; and in MDS-, EI- and II-profile statements, scientific relevance was discussed somewhat more than practical relevance.

The methodological issues were discussed clearly most in inquiry-oriented profiles and least in EDS and MDS profiles, leaving NDS profiles somewhere between the stances. Within the methodology, the II-profile statements addressed the use of methods more than other aspects, and much more than the statements from other profiles. The EI-profile statements focused on the choice and description of methods, and the EDS-profile statements concentrated on the description of methods. In the MDS-profile statements, the description of methods was discussed notably less than in other profiles. In the NDS-profile statements, all the methodological issues excluding the reflection upon methods were addressed quite evenly.

In the statements matching the MDS-profile, questions related to the research process were commented upon the least of the profiles. Comments in this area were most common in EDS- and II-profile statements, but they focused on quite different topics, with EDS-profile-related statements discussing the empirical work, and II-profile-related statements discussing the formulation of the research questions. Otherwise, the discussion on research process was rather evenly distributed across the different profiles and different topics.

Aspects regarding the written presentation of the dissertation work were addressed quite similarly in the statements related to the different profiles. In all profiles, most attention was focused on the logic of the presentation, and relatively less on referencing and compliance with the standards of scientific writing.

Using peer review as an indicator of research quality was less common in the field-oriented profiles of NDS- and II-profile statements than in others. Judging the research quality against the standards for scientific work is more common in the research-oriented profiles of EI and II than in the design-oriented profiles of EDS, MDS and NDS. Discussing research quality through the aspects of truth-value, applicability, consistency, neutrality and utility was in general more common in II-profile statements than in other profile statements. Of these aspects, EDS- and MDS-profile statements seemed to focus on utility, NDS-profile statements on applicability, and EI- and II-profile statements on consistency.

7.5. Differences and similarities among faculties

The general features of research as derived from the dissertations and the statements, and the presence of different research profiles in different faculties are discussed next. Findings regarding critical remarks and specific merits in statements in general as well as across the different profiles and different faculties are presented separately in section 7.6.

7.5.1. General features of research

The findings concerning dissertations in all of the faculties are displayed in Table 22, and the most notable aspects related to the findings are commented upon. The most visible difference in the totality of findings concerning the faculties likely was the contrast of the strong presence of the philosophical discussion in the Faculties of Built environment (FBE) and Business and Technology Management (BTM) with the almost complete absence of this discussion in all other faculties. This was especially evident in the explication of the conception of science. In the Faculty of Computing and Electrical Engineering (CEE), four of the 21 dissertations followed a described or named conception of science. In the dissertations done in the Faculties of Automation, Mechanical and Materials Engineering (AMM) and Science and Environmental Engineering (SEE), none of the dissertations addressed this issue.

The same division into two camps could also be observed with respect to the research objectives. In the Faculties of AMM, SEE and CEE, the great majority of dissertations contained the objective to design (something). In the Faculties of FBE and BTM, to describe was stated as an objective of the inquiry more often than in design-oriented faculties. The same also applied to the objective to interpret.

Table 22. Features of engineering science in dissertations according to the different faculties

		AMM (N=9)	**SEE (N=10)**	**FBE (N=4)**	**CEE (N=21)**	**BTM (N=6)**
Philosophical commitments						
	Conception of science	0 %	0 %	75 %	19 %	83 %
	Epistemology	11 %	10 %	25 %	10 %	33 %
	Ontology	0 %	25 %	25 %	5 %	33 %
	Ethics	0 %	0 %	0 %	0 %	17 %
	Not mentioned	89 %	90 %	0 %	76 %	17 %
Research objectives						
	To describe	44 %	50 %	75 %	24 %	67 %
	To design	100 %	90 %	50 %	95 %	50 %
	To explain	11 %	30 %	50 %	14 %	33 %
	To interpret	0 %	10 %	50 %	5 %	33 %
Function of empirical work						
	To advance a design	22 %	70 %	25 %	24 %	33 %
	To create knowledge	44 %	70 %	100 %	33 %	67 %
	To test a construction	44 %	0 %	25 %	67 %	33 %
Form / type of empirical work						
	Field research	33 %	10 %	100 %	38 %	100 %
	Laboratory work	56 %	60 %	0 %	29 %	0 %
	Prototyping	0 %	10 %	0 %	19 %	0 %
	Simulation	33 %	20 %	0 %	48 %	0 %
Methodology						
	Data acquisition	78 %	70 %	100 %	62 %	83 %
	Data analysis	89 %	80 %	100 %	57 %	83 %
	Modelling/design	56 %	60 %	0 %	71 %	33 %
	Preparation	33 %	40 %	0 %	10 %	0 %
	Case method	22 %	10 %	75 %	24 %	50 %
	Research approach	11 %	10 %	75 %	19 %	83 %
Type of resulting knowledge						
	Know-how	89 %	60 %	50 %	67 %	50 %
	Know-that	44 %	80 %	50 %	62 %	50 %
	Know-what	22 %	0 %	0 %	5 %	0 %
	Know-why	0 %	10 %	50 %	10 %	33 %
Explicated contribution						
	Artefact	33 %	10 %	0 %	48 %	0 %
	Knowledge	33 %	20 %	75 %	33 %	67 %
	Method	67 %	10 %	25 %	43 %	67 %
	Proposal	22 %	10 %	0 %	10 %	17 %
	Not named	33 %	80 %	25 %	43 %	33 %
Quality aspects addressed						
	Truth-value	22 %	40 %	75 %	38 %	83 %
	Applicability	22 %	20 %	75 %	33 %	100 %
	Consistency	67 %	30 %	50 %	29 %	83 %
	Neutrality	0 %	0 %	25 %	10 %	50 %
	Novelty	11 %	10 %	0 %	24 %	17 %
	Publicity	0 %	10 %	0 %	0 %	0 %
	Utility	78 %	50 %	50 %	71 %	100 %
	Nothing	0 %	20 %	0 %	10 %	0 %
Quality measures used						
	Measures of truth-value	0 %	20 %	50 %	14 %	67 %
	Measures of applicability	11 %	10 %	50 %	14 %	83 %
	Measures of consistency	33 %	10 %	50 %	14 %	83 %
	Measures of neutrality	0 %	10 %	50 %	5 %	50 %
	Measures of utility	67 %	50 %	25 %	62 %	33 %
	Nothing	22 %	50 %	25 %	29 %	0 %

Regarding the empirical work, some notable differences lay in both function and form. Compared to other faculties. empirical work was most often used to advance a design in the Faculty of SEE and to test a construction in the Faculty of CEE. The function of creating knowledge was less common in the Faculties of AMM and CEE than in others. The form of the empirical work was strongly related to the given faculty. In the Faculties of FBE and BTM, all the dissertations included field work, whereas in the Faculty of SEE, the laboratory work was the clearly dominant form of empirical work. In the Faculty of CEE, all four types of empirical work were quite evenly present, with simulation being the most common type.

Methodological differences went hand in hand with empirical differences. In the Faculties of FBE and BTM, the methodology used and described related more to the data acquisition and analysis than to modelling and design. In the Faculties of AMM, SEE and CEE, the design methodology was explicated alongside the more traditional research methodology. Case method was used in all faculties, but as noted earlier, the understanding and in turn the application of it changed a greatly. In the Faculties of FBE and BTM, methods were more often accompanied with the presentation of a wider research approach than in other faculties.

The knowledge resulting from the dissertation work was of a different type in different faculties. In the Faculty of AMM, the resulting knowledge was dominantly of know-how type, whereas in the Faculty of SEE, know-that is the most common form of knowledge. The explication of contribution was quite uncommon in the Faculty of SEE, but rather customary in other faculties. In the Faculty of AMM, the explicated contributions were usually methods, and in the Faculty of FBE, these were knowledge. In the Faculty of BTM, the explicated contributions were typically knowledge or methods. In the Faculty of CEE, artefact was the most common form of contribution, but knowledge and methods were also often acknowledged as contributions.

Of all the aspects of research quality, utility was the only one clearly addressed in all faculties. In all but one, the Faculty of FBE, it was also the quality aspect most often discussed. The other three aspects of quality were varyingly dealt with, with consistency being the issue in the Faculty of AMM, truth-value and applicability in the Faculty of FBE, all three aspects of quality in the Faculty of BTM, and truth-value coming next to utility in the Faculties of SEE and CEE. Concerning quality measures, the story was slightly different. The measures of utility were the most commonly used quality measures in the Faculties of AMM, SEE and CEE, but in the Faculty of BTM, the measures of applicability, consistency and truth-value were used more often than the utility measures. Half of the dissertations of the Faculty of SEE had no measures of quality applied to the evaluation of the research work.

7.5.2. Statements of dissertations from different faculties

Statements from different faculties concerning dissertations were dissimilar, and they focused attention on entirely different matters. The faculties gave different instructions to the examiners, which naturally affected the direction of the attention to some extent.

However, by in large, the instructions were so general that they were unlikely to produce any major differences in the content of the statements.

The two smallest faculties, the Faculty of Built Environment (FBE) and the Faculty of Business and Technology Management (BTM), were most alike in terms of the statements. All of the dissertations in these faculties included field research (see Table 22 on page 128), which probably also directs the attention of the examiners towards a certain direction. The remaining three faculties were most similar to each other with respect to the issues of presentation and quality aspects addressed. Yet, in the matters of methodology and research process, there were notable differences among the commenting. All findings according to faculty are presented in more detail in Table 23.

In the Faculty of BTM, the theoretical background was more often considered to occupy the role of research framework than to demonstrate knowledge, whereas in other faculties, this was the opposite. In all of the faculties, the relevance of the dissertation research was addressed in statements to nearly the same extent. However, in the Faculty of SEE, scientific relevance was brought up more often than practical relevance; in the Faculties of AMM and FBE, practical relevance was mentioned more than scientific relevance; and in the Faculties of CEE and BTM, both relevances were addressed equally often.

The research philosophy was most commonly noted in the Faculty of FBE statements. This was to be expected, as the presence of research philosophy was also the strongest in FBE dissertations. However, the relatively strong presence of philosophical considerations in the Faculty of BTM dissertations was not reflected in the statements.

Methodology was clearly commented upon the most in the Faculty of BTM statements, and clearly the least in the Faculty of AMM statements. Among the methodological issues, the Faculty of BTM emphasised the use of methods, and the Faculty of SEE stressed the description of methods. Other faculties addressed all the methodological issues quite evenly, except for that of the reflection upon methodologies, which was rarely brought up in all of the statements. The fewest comments on methodology were in the Faculty of AMM, which did have, however, the most comments on the research process.

The quality of research was varyingly addressed in the faculties. In the Faculty of SEE, peer review as an indicator of research quality was strongly present in the statements, whereas discussion about the aspects of research quality was not common. In the Faculty of TBE, the situation was the opposite. In the Faculty of BTM, both approaches to quality were present in the statements to some degree, and quality was also perceived as compliance to scientific standards or as fitness for purpose. In the Faculty of CEE, the quality issues were also addressed more through peer review than through quality aspects, but not as much as in the Faculty of SEE. Finally, in the Faculty of AMM, the quality discussion was rather scattered through the different perceptions of research quality.

Table 23. Features of engineering science in statements regarding dissertations from the different faculties

	AMM (N=27)	**SEE (N=30)**	**FBE (N=12)**	**CEE (N=63)**	**BTM (N=17)**
Research philosophy	**4 %**	**7 %**	**42 %**	**2 %**	**6 %**
Role of theoretical background	**44 %**	**57 %**	**67 %**	**51 %**	**82 %**
To build a framework	19 %	20 %	33 %	19 %	71 %
To demonstrate knowledge	37 %	47 %	42 %	44 %	47 %
Relevance	**70 %**	**80 %**	**58 %**	**67 %**	**88 %**
Scientific relevance	48 %	70 %	25 %	49 %	71 %
Practical relevance	59 %	50 %	50 %	49 %	71 %
Methodology	**30 %**	**60 %**	**75 %**	**59 %**	**94 %**
Choice of methods	15 %	23 %	33 %	35 %	53 %
Description of methods	11 %	43 %	33 %	25 %	59 %
Reflection upon methods	0 %	7 %	8 %	3 %	18 %
Research design	4 %	13 %	50 %	16 %	35 %
Use of methods	15 %	27 %	50 %	21 %	71 %
Research process	**78 %**	**50 %**	**58 %**	**70 %**	**65 %**
Coherence of process	41 %	20 %	33 %	22 %	24 %
Empirical research	37 %	33 %	33 %	29 %	24 %
Formulation of research question	0 %	3 %	17 %	16 %	29 %
Validation/convincing/verification	30 %	20 %	42 %	30 %	24 %
Presentation	**52 %**	**60 %**	**92 %**	**56 %**	**71 %**
Logic of presentation	33 %	43 %	75 %	37 %	59 %
Referencing	7 %	17 %	17 %	19 %	12 %
Text in line with scientific standards	26 %	13 %	17 %	13 %	12 %
Quality definitions	**48 %**	**77 %**	**42 %**	**59 %**	**59 %**
"Good quality"	4 %	20 %	8 %	8 %	0 %
Fitness for purpose	11 %	3 %	0 %	5 %	18 %
Peer review	33 %	67 %	25 %	49 %	47 %
Work in line with scientific standards	0 %	7 %	17 %	6 %	18 %
Quality aspects addressed	**37 %**	**37 %**	**67 %**	**37 %**	**65 %**
Truth-value	7 %	7 %	25 %	10 %	35 %
Applicability	15 %	13 %	33 %	13 %	35 %
Consistency	11 %	20 %	33 %	8 %	47 %
Neutrality	4 %	3 %	8 %	0 %	18 %
Utility	15 %	7 %	8 %	16 %	24 %

Among the quality aspects discussed, there truly appeared to be no specific preferences among the faculties, apart from consistency, which was addressed in nearly half of the Faculty of BTM statements. As noted at the general level of all statements, utility did not seem to be as dominant of an aspect of quality in statements in any of the faculties as it was in the dissertations. The possibility exists, however, that what was discussed in dissertations as the utility of the results was in statements addressed as the practical relevance of the dissertation work.

7.5.3. Research profiles in different faculties

Although the research profiles did not follow the organisational boundaries of the faculties, the connection between certain profiles and faculties was stronger in some cases than in others. Nevertheless, there were dissertations from virtually all of the faculties in nearly all of the research profiles. The distribution of the profiles and faculties and the location of shared dissertations are illustrated in Table 24.

Table 24. Relationship between the faculties and the research profiles

	AMM (N=9)	SEE (N=10)	FBE (N=4)	CEE (N=21)	BTM (N=6)	“shared”
Experimental design science EDS (N=21)	6	6	1	8	0	10
Mathematical design science MDS (N=12)	1	2	0	9	0	5
Naturalistic design science NDS (N=20)	3	2	2	9	4	9
Explanatory inquiry EI (N=5)	1	2	0	1	1	3
Interpretive inquiry II (N=7)	0	1	2	2	2	3
“shared”	2	3	1	9	1	

The Faculties of AMM and CEE had the strongest design science orientation, with only a small fraction of the dissertations expressing explanatory or interpretive inquiry features. The biggest difference between the types of research conducted in these two faculties was the much stronger presence of mathematical design science in the Faculty of CEE than in that of AMM. In the Faculty of CEE, all three design science profiles were rather evenly present, whereas in the Faculty of AMM, the emphasis was on experimental design science.

The Faculties of FBE and BTM were rather similar in terms of the research profiles, with a strong inclination towards naturalistic research, whether more design- or more inquiry-oriented. As a matter of fact, in the beginning of 2013, these two faculties merged into a new faculty: the Faculty of Business and built environment.

The distribution of different research profiles was the most even in the Faculty of SEE, with all of the research profiles present. Much of the research done from the Faculty of SEE was experimental, but mathematical and naturalistic research was conducted as well. In the Faculties of SEE and CEE, about one-third of the dissertations expresessed features of more than just one research profile, which also points to the diversity of the research conducted.

7.6. Critical remarks and specific merits

In order to understand which issues are especially challenging in engineering research, quotations containing criticism were coded in the statements alongside the implementation of the regular coding scheme. Although statements varied in the level of critique, the average amount of critical remarks per statement was calculated to indicate the general level of criticism towards certain issues in each group of interest.

In addition, specifically positive remarks were coded with a similar procedure in order to understand what was perceived as remarkable or particularly valuable in dissertations. These remarks did not include all the comments that could have been regarded as positive, such as “the text is of good quality,” but rather included only what was considered as unusually good for a dissertation or what was pointed out as a special strength or asset of a dissertation.

The grade awarded for the dissertation was regarded as another sign of specific appreciation of the conducted research. Thus, the dissertations awarded the grade “pass with distinction” were compared to the dissertations awarded the grade “pass” to determine how they were different from each other.

In the coding scheme and in the presentations of earlier findings from the statements, theoretical background was discussed from the viewpoint of its role in dissertation work. Quality issues were remarked upon from the standpoints of general perceptions concerning quality and of quality aspects addressed. When the critical and laudatory comments were analysed, these perspectives were slightly altered, as the interest now lay not in the examiner’s perception of the topic but in his or her judgement made about it. Thus, the examiner’s judgements were targeted at the theory included and presented in the dissertation, instead of being targeted at the role of the theoretical background (despite the examiner’s perception of the role of the theoretical background). Similarly, a comment made about the exceptionally high quality of the journals in which the articles from a compilation dissertation had been published was viewed in this context as an appraisal targeting the quality of the dissertation research. In other parts of the analysis, this kind of comment signified the examiner’s perception of peer review as a quality indicator. Hence, the term *theoretical background* is used instead of *the role of theoretical background*. The term *quality issues*, which includes all items pointing to research quality, is also used herein.

7.6.1. Targets of criticism

What received the most criticism is introduced here in two complementary ways. First, criticism directed at each of the coding-scheme categories is noted in order to determine how challenging certain issues seem to be in total, in different faculties and in the various research profiles. Then, the most challenging topics; i.e., the most critiqued aspects of the dissertations, are revealed in more detail. The level of criticism is expressed as an average of critical remarks per statement. The issue is examined at both faculty and profile levels in order to understand what kind of sub-disciplinary differences there are under the focus of critical examination and to see what the challenging features of different types of research are.

Table 25 presents the average amount of critical comments per statement in the statements regarding the dissertations from different faculties. All in all, the most criticism was directed at the methodological issues in all the faculties as well as in the statements in total. The levels of criticism among the different faculties should not be compared, as the numbers of dissertations from the faculties are so different, and thus one statement containing a good deal of criticism has much larger effect in the smaller faculties than in the bigger ones. The same applies to the comparison of the levels of criticism among the profiles, presented in Table 26.

What can be viewed, however, are the levels of criticism among the different topics within the faculties and profiles, as the sharpest critiques were typically targeting many of the aspects regarding the dissertation (hence the large number of critical comments in the same statement). In total, most criticism was directed at methodology. The research process, theoretical background, presentation and quality issues received some criticism, too; whereas the relevance of the dissertations was rarely criticised, and the research philosophy was barely touched upon.

Table 25. The average number of critical comments per statement in total and in the statements pertaining to dissertations from the different faculties

Critical remarks per statement	**all statements**	**AMM**	**SEE**	**FBE**	**CEE**	**BTM**
Research philosophy	0.03	0.00	0.00	0.42	0.00	0.00
Theoretical background	0.30	0.04	0.30	0.50	0.29	0.53
Relevance	0.13	0.00	0.23	0.17	0.13	0.18
Methodology	0.65	0.33	0.33	1.08	0.89	0.53
Research process	0.32	0.00	0.27	0.42	0.46	0.29
Presentation	0.26	0.19	0.07	0.58	0.38	0.12
Quality issues	0.23	0.07	0.10	0.58	0.24	0.41

In the Faculty of Automation, Mechanical and Materials Engineering (AMM), the only issues receiving criticism were methodology and presentation. In the faculty of Science and Environmental Engineering (SEE), the theoretical background and the research process were criticised nearly as often as the methodology. Relevance issues received some criticism, too. In the Faculty of Built Environment (FBE), the methodology received the most criticism, and relevance the least. All the other topics were criticised quite equally. The statements of the dissertations from the Faculty of Computing and Electrical Engineering (CEE) paid the most critical attention to the methodology, the research process and the presentation. Additionally, the theoretical background was addressed critically to some extent. In the Faculty of Business and Technology Management (BTM), the theoretical background was criticised as much as the methodological issues. Quality issues were also critically discussed rather often, and the research process to some degree as well.

In terms of the profiles, the methodology was also the most critiqued point. In the explorative inquiry (EI)-profile statements, however, there were no critical comments concerning methodology. In fact, the theoretical background was the only aspect really criticised among the EI statements. In the engineering design science (EDS)- and mathematical design science (MDS)-profile statements, criticism was directed at the methodology and the presentation. The research process and theoretical background were also criticised, but to lesser extent. In the naturalistic design science (NDS)-profile statements, most of the critique centred around the methodology, and after that the research process, the presentation, the quality issues and the theoretical background were all criticised rather evenly. Interpretive inquiry (II)-profile statements also criticised the methodology the most, but the research process came quite close as well as the theoretical background. Relevance and quality issues also concerned the examiners of the II profile to a small extent.

Table 26. The average number of critical comments per statement in the statements regarding the dissertations categorised under the different research profiles

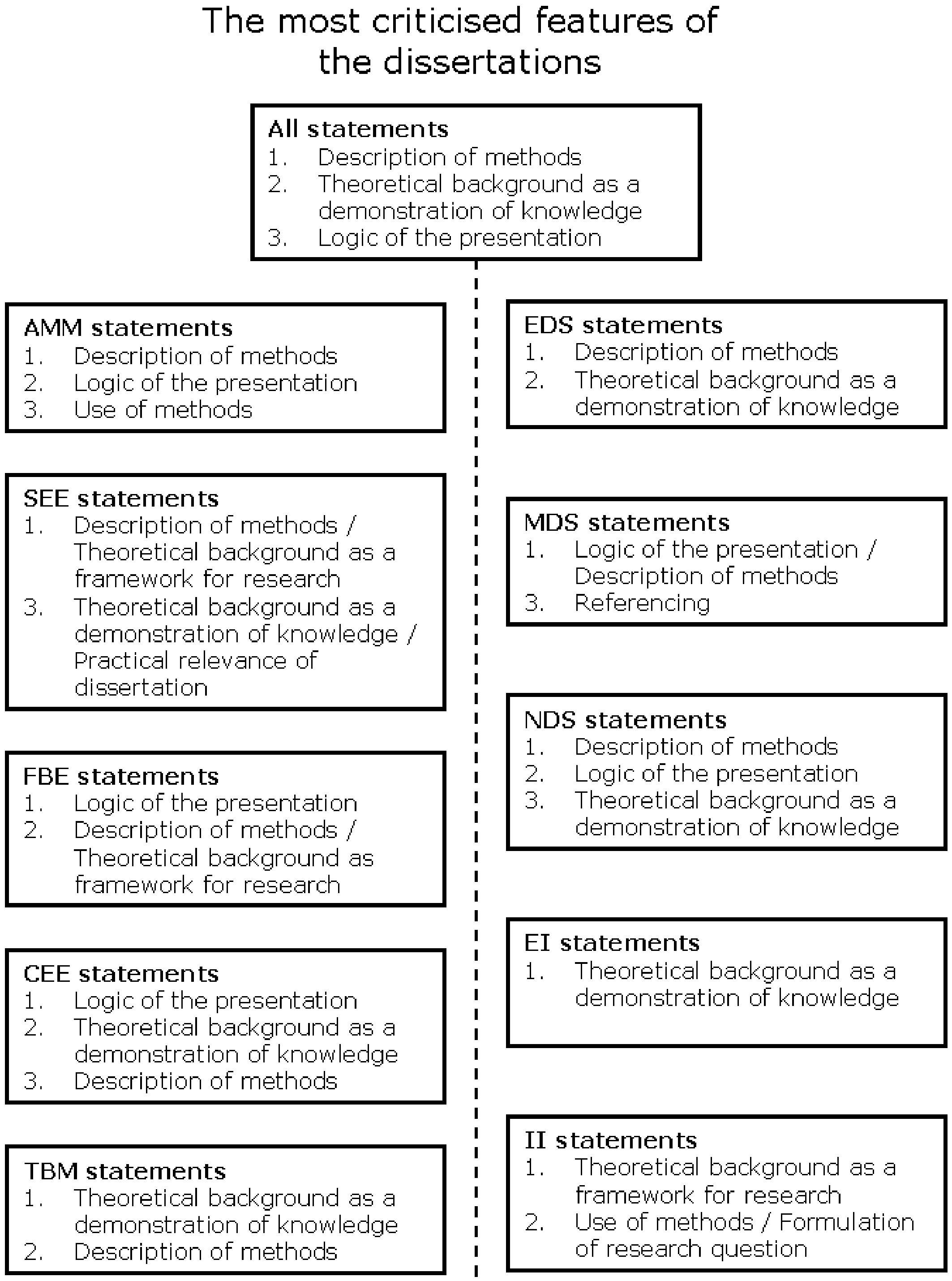
Critical remarks per statement	**EDS**	**MDS**	**NDS**	**EI**	**II**
Research philosophy	0.00	0.00	0.05	0.00	0.10
Theoretical background	0.11	0.19	0.34	0.27	0.90
Relevance	0.03	0.11	0.19	0.07	0.50
Methodology	0.33	0.75	0.85	0.00	1.35
Research process	0.14	0.28	0.39	0.07	1.10
Presentation	0.22	0.39	0.37	0.00	0.35
Quality issues	0.03	0.14	0.36	0.07	0.55

A more detailed look at the targets of criticism reveals that the description of methods is not only the most criticised issue at the general level of all the statements, but also the most criticised in all the faculties, as illustrated below in Figure 17.

The theoretical background was of concern to the examiners for all faculties other than the Faculty of AMM. However, in the Faculties of SEE and FBE, the primary concern aimed towards the theoretical background seems to be connected to its role as a framework for research, whereas in the Faculties of CEE and BTM, examiners paid more critical attention to the level of knowledge which the theoretical background demonstrates. The logicality of presentation received criticism in the cases of the Faculties of AMM, FBE and CEE.

In all of the design-oriented research profiles, the description of methods was the single most criticised aspect. In the case of the research-oriented profiles, the biggest concerns lay in the theoretical background; in the II profile as a framework for research and in the EI profile as a demonstration of knowledge. The demonstration of knowledge via the theoretical background was among the top issues of criticism also in the dissertations assigned the EDS and NDS profiles. As for the MDS-profile dissertations, the logic of the presentation and the referencing seemed to cause challenges for candidates, whereas in the II-profile theses, the problems lay more in the formulation of research questions and the use of research methods.

All of this suggests that the focus of the evaluation of the dissertation work varies slightly according to the subdisciplines, represented here by the faculties, and the different nature of the research work, represented here by the research profiles. In this study, it is assumed that the criticism denotes those issues where the performance level expected by the scientific community, as represented by the examiners, is most difficult to achieve. Hence, the criticism points in turn to the topics which are most challenging for the doctoral candidates.



The most criticised features of the dissertations

All statements
1. Description of methods
2. Theoretical background as a demonstration of knowledge
3. Logic of the presentation

AMM statements
1. Description of methods
2. Logic of the presentation
3. Use of methods

SEE statements
1. Description of methods / Theoretical background as a framework for research
3. Theoretical background as a demonstration of knowledge / Practical relevance of dissertation

FBE statements
1. Logic of the presentation
2. Description of methods / Theoretical background as framework for research

CEE statements
1. Logic of the presentation
2. Theoretical background as a demonstration of knowledge
3. Description of methods

TBM statements
1. Theoretical background as a demonstration of knowledge
2. Description of methods

EDS statements
1. Description of methods
2. Theoretical background as a demonstration of knowledge

MDS statements
1. Logic of the presentation / Description of methods
3. Referencing

NDS statements
1. Description of methods
2. Logic of the presentation
3. Theoretical background as a demonstration of knowledge

EI statements
1. Theoretical background as a demonstration of knowledge

II statements
1. Theoretical background as a framework for research
2. Use of methods / Formulation of research question

Figure 17.The most criticised features of the dissertations in the different faculties and research profiles

7.6.2. Praised features and distinguished dissertations

Of the 50 dissertations in the data, nine were awarded the grade “pass with distinction.” Two of these dissertations were monographs, and seven were compilations, which renders the monograph dissertations as being slightly underrepresented among the distinguished dissertations.

The breakdown of the numbers of distinguished dissertations within the five research profiles was three in EDS, four in MDS, one in NDS, one in EI and none in II. This is somewhat reflected in the features of the distinguished dissertations as opposed to the ones awarded the grade “pass,” as can be seen in Table 27. The dissertations which passed with distinction included fewer philosophical considerations, more explanatory objectives, fewer interpretive objectives, much more simulation work, more know-that knowledge but no know-why knowledge as results compared to the other dissertations. All the distinguished dissertations included a discussion about quality aspects in general; but the aspects of truth-value, applicability and neutrality were, on average, discussed and evaluated less than in the other dissertations.

The examination of the distinguished dissertations suggests that a mathematical orientation and numerical simulation are typical for being the most highly lauded engineering science research. Interestingly enough, the laudatory comments in the statements point to another direction.

In general, there were fewer laudatory remarks than critical comments in the statements in all the faculties except for that of AMM, and all of the research profiles except for that of EI. For the dissertations under the profile of EDS, the number of positive and critical comments was the same. Table 28 presents the average of positive comments per statement in the statements pertaining to the dissertations from different faculties, and Table 29 does the same for dissertations categorised under the different profiles. Once again, it should be remembered that in this matter also, faculties or profiles themselves should not be evaluated against each other due to the differing numbers of statements in each group.

At the general level of all the statements, the research process was the area receiving the most praise. Although being the most problematic area, methodology was also among the most lauded issues at this general level, as can be seen in Table 28. The research process entailed the most valued aspects in the case of the Faculties of AMM, FBE and CEE. The methodology took first place for the Faculties of SEE and BTM. In addition to these, the positive attention received by the theoretical background in the Faculty of AMM and quality issues in Faculty of BTM should also be noted. The research process and/or the methodology were the areas also earning praise for the dissertations in the different research profiles. The research process especially received credit in statements pertaining to the dissertations assigned to the EDS, NDS and II research profiles. Methodological issues were given the most credit in the MDS- and EI-profile statements. In the EI-profile statements, the theoretical background was also positively commented upon.

Table 27. Features of engineering science in dissertations passed with distinction and in others which passed

		Passed with distinction (N=9)	Passed (N=41)
Philosophical commitments			
	Conception of science	11 %	27 %
	Epistemology	0 %	17 %
	Ontology	0 %	12 %
	Ethics	11 %	0 %
	Not mentioned	89 %	63 %
Research objectives			
	To describe	56 %	39 %
	To design	89 %	85 %
	To explain	33 %	20 %
	To interpret	0 %	15 %
Function of empirical work			
	To advance a design	33 %	34 %
	To create knowledge	56 %	51 %
	To test a construction	33 %	44 %
Form/type of empirical work			
	Field research	22 %	49 %
	Laboratory work	33 %	34 %
	Prototyping	0 %	12 %
	Simulation	67 %	22 %
Methodology			
	Data acquisition	44 %	78 %
	Data analysis	67 %	76 %
	Modelling/design	67 %	54 %
	Preparation	22 %	17 %
	Case method	11 %	32 %
	Research approach	22 %	29 %
Type of resulting knowledge			
	Know-how	56 %	68 %
	Know-that	78 %	56 %
	Know-what	11 %	5 %
	Know-why	0 %	17 %
Explicated contribution			
	Artefact	44 %	24 %
	Knowledge	44 %	37 %
	Method	44 %	41 %
	Proposal	11 %	12 %
	Not named	44 %	46 %
Quality aspects addressed			
	Truth-value	33 %	46 %
	Applicability	33 %	41 %
	Consistency	44 %	44 %
	Neutrality	0 %	15 %
	Novelty	11 %	17 %
	Publicity	0 %	2 %
	Utility	67 %	71 %
	Nothing	0 %	10 %
Quality measures used			
	Measures of truth-value	11 %	24 %
	Measures of applicability	11 %	27 %
	Measures of consistency	22 %	29 %
	Measures of neutrality	0 %	17 %
	Measures of utility	56 %	54 %
	Nothing	22 %	29 %

Table 28. The average number of positive remarks per statement in total and in the statements pertaining to the dissertations from the different faculties

Positive remarks per statement	**all statements**	**AMM**	**SEE**	**FBE**	**CEE**	**BTM**
Research philosophy	0.01	0.00	0.00	0.08	0.00	0.00
Role of theoretical background	0.11	0.33	0.07	0.00	0.05	0.12
Relevance	0.09	0.37	0.03	0.00	0.05	0.00
Methodology	0.20	0.19	0.23	0.00	0.13	0.59
Research process	0.23	0.41	0.20	0.17	0.24	0.18
Presentation	0.10	0.22	0.07	0.00	0.08	0.12
Quality issues	0.10	0.15	0.03	0.08	0.05	0.35

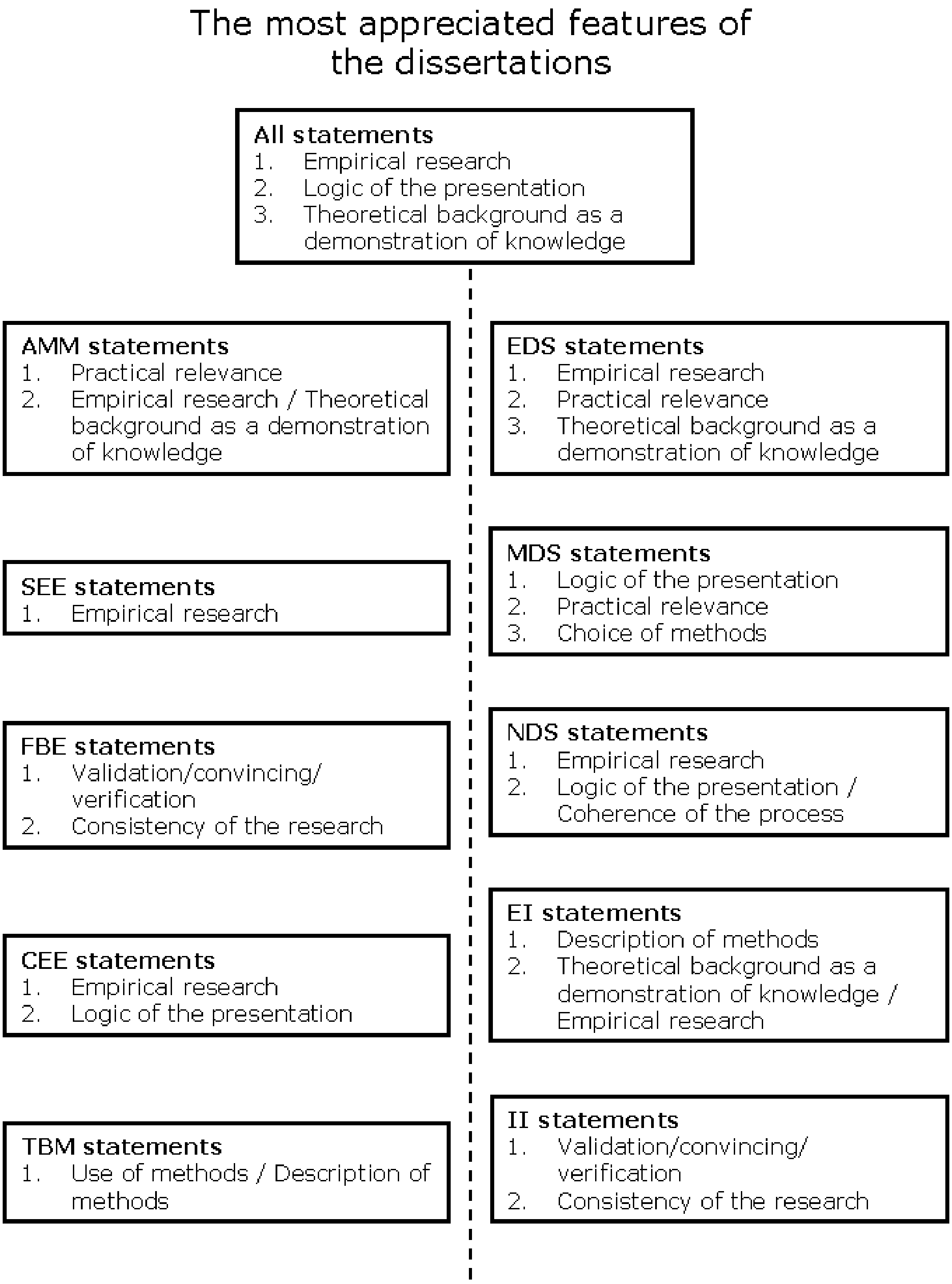
Table 29. The average number of positive remarks per statement in the statements pertaining to the dissertations assigned to the different research profiles

Positive remarks per statement	**EDS**	**MDS**	**NDS**	**EI**	**II**
Research philosophy	0.00	0.00	0.02	0.00	0.00
Role of theoretical background	0.14	0.03	0.08	0.27	0.00
Relevance	0.16	0.08	0.03	0.00	0.00
Methodology	0.14	0.17	0.12	0.87	0.00
Research process	0.25	0.08	0.25	0.33	0.10
Presentation	0.10	0.08	0.10	0.20	0.00
Quality issues	0.11	0.03	0.12	0.07	0.05

The details reveal that the most laudatory comments concerned the empirical research, both generally speaking as well as more specifically those found in statements from the Faculties of SEE and CEE. In the case of the Faculty of AMM, empirical research tied for second place after practical relevance. The most lauded aspects of the dissertations according to faculty or profile are depicted in Figure 18.

At the level of all statements, the logic of presentation and knowledge demonstrated in the theoretical background of the dissertation also received credit. These praised aspects were also present in the statements of the Faculties of AMM and CEE. The statements related to the dissertations from the Faculties of FBE and BTM seemed to positively comment upon totally different features. Interestingly, the description of methods was among both the most criticised and the most praised features in the Faculty of BTM.

An analysis shows that the empirical research was particularly commented upon in the statements connected with the research profiles of EDS, NDS and EI. Practical relevance was given credit in EDS- and MDS-profile-related statements. On the methodological side, the choice of methods was appreciated among the MDS-profile-related statements and the description of methods among the EI-profile-related statements. This is rather interesting, as the description of methods was also what was most criticised at the general level of all statements. The logic of presentation was especially valued in the statements related to the MDS- and NDS-research profiles.



The most appreciated features of the dissertations

All statements
1. Empirical research
2. Logic of the presentation
3. Theoretical background as a demonstration of knowledge

AMM statements
1. Practical relevance
2. Empirical research / Theoretical background as a demonstration of knowledge

EDS statements
1. Empirical research
2. Practical relevance
3. Theoretical background as a demonstration of knowledge

SEE statements
1. Empirical research

MDS statements
1. Logic of the presentation
2. Practical relevance
3. Choice of methods

FBE statements
1. Validation/convincing/ verification
2. Consistency of the research

NDS statements
1. Empirical research
2. Logic of the presentation / Coherence of the process

CEE statements
1. Empirical research
2. Logic of the presentation

EI statements
1. Description of methods
2. Theoretical background as a demonstration of knowledge / Empirical research

TBM statements
1. Use of methods / Description of methods

II statements
1. Validation/convincing/ verification
2. Consistency of the research

Figure 18.The most appreciated features of the dissertations according to the statements connected with the different faculties and research profiles

From the standpoint of the praised features, the Faculty of FBE statements and the II-research-profile statements seemed very different from the positive comments connected to the other faculties and profiles, respectively. Both entailed the most positive comments on the process of validation/convincing/verification and on the consistency of research. At the same time, it must be noted that these particularly positive comments from both sources were few in total.

7.7. Summary

This chapter has presented the reduced data from the empirical analysis. The reduction process was intentionally separated out from the interpretation and conclusions in order for the readers to be able to follow the analysis and to also draw conclusions of their own. Although many of the results were recorded as percentages, this was not intended to serve as a quantitative analysis, but instead to help one to see the qualitative trends in the different sets of data.

First, the data from all 50 dissertations were described with respect to the philosophical considerations, objective of research, nature of empirical work, methodology, research outcomes and evaluation of quality issues. The effect of gender-related differences and differences between monograph and compilation theses on the same issues were also elaborated upon.

Next, the five distinct research profiles that emerged from the data were described. To reflect the research objectives and type of empirical work prevailing in each profile, the profiles were named Experimental design science (EDS), Mathematical design science (MDS), Naturalistic design science (NDS), Explorative inquiry (EI) and Interpretive inquiry (II).

The data from the statements were first described as a whole and then according to the different profiles. This was done with respect to the research philosophy, role of theoretical background, relevance of research, methodology, research process, presentation and quality of research.

Differences and similarities among the faculties were noted according to the features in both the dissertations and statements. The relationship between the faculties and research profiles was studied, and it was noted that although the profiles did not follow the organisational boundaries, the connection between certain profiles and faculties was stronger amongst some cases than others. However, there were still dissertations from almost all of the profiles in almost all of the faculties.

Finally, both critical and positive remarks drawn from the statements were presented. Targets of criticism were noted with respect to the whole data, the different faculties and the different profiles. The same was done for the specific expressions of appreciation mentioned in the statements, and the data from the dissertations which “passed with distinction” was compared with data from the other dissertations.

The aim of this chapter was to present the data in a compact format and as neutrally as possible. In the next chapter, the data is interpreted and the resulting research findings are introduced.

8. Research findings

> *Historically and traditionally, it has been the task of the science disciplines to teach about natural things: how they are and how they work. It has been the task of engineering schools to teach about artificial things: how to make artifacts that have desired properties and how to design. (Simon 1996, 111)*

Simon (1996) defines the tasks of science and engineering, but leaves the task of engineering science undefined. The previous chapter presented the most striking similarities and differences among the 50 dissertations and 149 statements, which form the data of this study. The aim of this chapter is to build an understanding about the phenomenon of engineering science by bringing together the empirical observations, the previous theories and the philosophical discussions concerning the subject.

First, the coherence of engineering science is discussed. On the one hand, there seem to be some interlinking features of research that are quite consistent in the whole data; on the other hand, there are also clear differences between the dissertations and statements. Secondly, this divergence among the engineering sciences is discussed, and the five different profiles observed in the data are described and explained in more detail. Thirdly, the philosophy of engineering science is discussed from the viewpoints of a disciplinary matrix and the values and norms reflected in the data and literature.

8.1. Common features

Mitcham and Schatzberg (2009, 42) distinguish between the plural term *engineering sciences* and the singular term *engineering science* by defining engineering science (*Technikwissenschaft* in German) as the knowledge production activity internal to engineering or engineering sciences (*Technologie* in German). In practice, this means that the different engineering sciences, such as electrical engineering or mechanical engineering, would have lines of knowledge production sufficiently similar to each other to call this concept engineering science (in the singular). This study supports this view, at least with respect to the objectives and results, norms and quality criteria and challenges related to the research.

8.1.1. Strong design orientation

Simon (1996, 114) has suggested that the natural sciences concern themselves with how things are, and design with how things ought to be. Van Aken (2004) and Hevner et al. (2004) have argued that the task of design science is to produce knowledge related to constructing and evaluating solutions to problems in a certain application domain.

This was also clearly visible in the data. Most of the dissertations held the objective of constructing, evaluating, improving or demonstrating something.

> *The objective of this thesis is to develop completely automatic 3D brain MR image analysis methods…[P36]*
>
> *The objective of this thesis is also to evaluate the use of reliability worth and interruption costs in the reliability-based network analysis and planning. [P27]*
>
> *The goal of the present research is to improve the quality and efficiency of balancing paper machine rolls…[P6]*
>
> *Another goal was to show that the allowable total thermal expansion length of a fully integral bridge can be determined by the presented research process on the basis of structural behaviour. [P20]*

Even those dissertations which aimed at explaining causalities usually also contained design-oriented objectives.

The design orientation also shows up in the role assigned to the empirical work in the dissertations. In most of the dissertations, the empirical work was done in order to test a method or a construction or in order to advance a design. Both of these purposes set for the empirical work are likely not common in the framework of theory testing or of creating research, but they are essential elements in constructing and evaluating new solutions to or problem-solving models for practical problems.

Interestingly, when it comes to methodology, the design orientation is less evident. Although most of the dissertations held design-related objectives, little over half of the dissertations reported the usage of systematic methods for modelling or designing a construction. Instead, methods for data acquisition or data analysis were more frequently described.

The methods used for modelling or designing a construction varied from very specific methods intended for very specific design tasks to rather general aids for advancing a design, such as systems thinking.

> *The Studies on the PSI/SI robustness was continued with TU6 simulations…[P42]*
>
> *As already mentioned above the molecular dynamics simulation method is the method of choice in most of the recent pressure profile studies as well as in all publications in this thesis. [P13]*
>
> *Construction is carried out using a Pattern mining method and evaluation is based on Q-PAM. [P37]*
>
> *In the research a system approach will be used. In a system approach general conceptual and abstract structures and parts are described. A system is described as models that are simplified and subjective descriptions of the phenomenon. [P46]*

Sometimes the methods used were not named, but nevertheless described, in order to make the design process explicit.

> *First, a basic version of the method is developed and evaluated. Then, with deeper understanding of the subject, an advanced version is developed and evaluated. [P47]*

In looking at the results and contributions of the dissertations, the design orientation is reflected in the know-how type of knowledge. This was the most commonly produced knowledge type, as it was created in two-thirds of the dissertations. When the contributions of the dissertations were distinctly identified, they were most often methods; but knowledge, artefacts and proposals were also named as contributions.

Here, some differences between the faculties could be detected, with the dissertations from the Faculty of Automation, Mechanical and Materials Engineering contributing more often in terms of methods, and the dissertations from the Faculty of Computing and Electrical Engineering contributing more in terms of artefacts.

All in all, the majority of the dissertation research done in the different engineering sciences seems to more or less fit the characterisation of design science. This does not apply to all of the research, which becomes more evident when the research profiles are described in more detail, but it does suggest that the basic ideas of design science deserve to be introduced to all engineering science researchers.

8.1.2. Utility as a norm

The role of utility in engineering science was discussed from a theoretical viewpoint in section 3.1.1. Here, the quite commonly stated belief of natural science aiming for truth and engineering science aiming for utility was presented and challenged. It was also suggested that Houke's (2009) critique is mainly directed at the assumption of truth as the objective of science and not at the assumption of usefulness as the objective of technology and engineering science. Thus, it does not really challenge, for instance, Hendricks et al.'s (2000) view that truth is to some extent less important for engineering science than is utility.

In light of these empirical results, utility certainly seems to be "the norm" for engineering scientists. In the 50 dissertations, it was by far the most discussed aspect and most used measure for quality. Utility does, however, have many facets, ranging from financial to technological ones, and sometimes even to social or cultural ones.

> *Compared with these competing technologies, the suggested measurement system is competitive when the energy efficiency is considered. [P8]*
>
> *The current and near future of an exposition on EEG measurement sensitivity distributions will benefit many clinical neurophysiologists such as anesthesiologists, neurologists, and cognitive neuroscientists. [P11]*
>
> *The developed frameworks can be for major help in decision-making for SMEs.[P12]*
>
> *The method, however, provides rather low time resolution and requires many identical samples just for one time-resolved graph, which makes it expensive and time-consuming. [P10]*

In the statements, utility-related issues were mentioned much less than in the dissertations. These issues were also no more commonly addressed than the aspect of truth-value, and less frequently addressed than the aspects of applicability and consistency. Nevertheless, the broader notion regarding the practical relevance of the dissertation research was noted in just over half of the statements, with references to the technological, commercial or societal significance of the work done. This suggests that utility is also considered to be important in the statements, although only few explicit remarks of the more specific utility evaluations were presented.

8.1.3. Confusion about quality

Scientific research is commonly related to aspects of quality such as truth-value, applicability, consistency and neutrality. These were discussed in section 2.5.1, along with their related links to the norms of science and to the suitability for positivistic and naturalistic research traditions. Although the quality of scientific research is in general debated a fair amount, quality in engineering science research and the suitability of the contemporary quality aspect for engineering science is hardly discussed. Instead, the general norms of science and the quality measures used in natural science often also serve as the status quo for engineering science researchers (see e.g. Airila & Pekkanen 2002).

Discussion about the evaluation of the quality of design science research is seemingly also scarce. Simon (1996), Hevner et al. (2004) and van Aken (2004) all address the relevance vs. rigour question as well as the importance of utility-related criteria (see section 2.6.3. for more detail). According to Hevner et al. (2004, 88), "design-science researchers must constantly assess the appropriateness of their metrics and the construction of effective metrics is an important part of design-science research." All of this still remains at a rather general level and may be difficult to implement into engineering science research.

As noted in the previous section, utility is the most discussed quality aspect in the dissertations. It was somehow addressed in more than two-thirds of all the dissertations, whereas the aspects of truth-value, applicability and consistency were each discussed in less than half. Four out of 50 dissertations contained no kind of references to any aspects of quality regarding either the process or the results of the research.

Trying to measure or evaluate quality seems even more challenging than discussing it: just over half of the dissertations contained some measures for assessing the utility of the research, and just about a quarter of the dissertations contained measures to assess the truth-value, applicability or consistency of the research. Just over a quarter of the dissertations contained no attempts to assess quality of any kind.

Bringing in the statements makes the picture even more fragmented. The quality of dissertations was evaluated in the statements in many different ways. The most common way to ensure dissertation quality was to refer to the peer review processes. This was done in nearly half of the statements. The quality-aspect approach (i.e., discussing the utility, truth-value, applicability, consistency and/or neutrality issues) was adopted in a little under half of the statements. In some cases, quality was addressed by stating that the work is in line with scientific standards or by acknowledging that the work was "fit for purpose" or of "generally good quality." More than one-fifth of the statements made no remarks regarding the quality of the dissertation or the attempts made (or not made) in the dissertation to evaluate quality.

The question "How does one assess the quality of engineering science research?" thus seems to have no clear answers. In fact it is not even clear as to whether the quality should be assessed. Although contemporary measures such as reliability and validity work in some of the research profiles, as explained later, the majority of the research does not find them applicable. However, there seems to be nothing to offer to replace the quality tools adopted from other sciences either. About half of the writers of the statements appear to be happy with the quality of the dissertation if the parts of the dissertation (articles) have passed the peer review. Even if this is found as a satisfactory quality assurance for compilation dissertations, it does not solve the issue with respect to monographs. This peer-review quality assurance method provides also no help for the researcher as to evaluate or enhance the quality of his/her research before the research has proceeded to the publication phase.

8.1.4. Challenges for junior researchers

Hendricks et al. (2000) suggest that in engineering science, methods are more fundamental than theory. They additionally state that the use of theory is eclectic and polyparadigmatic, and that methods are used in order to provide useful design data rather than to assess hypotheses.

Judging from the statements in the data, the greatest challenges associated with the dissertation research are the description of methods, the theoretical background and the logic of the presentation of the research. This is easy to understand in light of the statement above, especially if one (even subconsciously) holds an image of natural science research where a certain theory is tested by applying the pertinent methods.

When the methods are more fundamental to the research than the eclectically used theory, it may be difficult to select the most appropriate ones, as they are not defined or necessarily even limited by theory. In some cases, several methods can provide useful design data, and in other cases, none can. A design often evolves in iterative circles, with the methods for obtaining the data developing alongside the design. This can make describing the methods a challenging task, as it is difficult, if not impossible, to determine where the method ends and the design begins.

> *The description of the experiment is not clear. First you do not say enough how the coil was manufactured.: winding like a solenoid? Did you use the pancake (double pancake) technique?... Finally the results of the measurement must come before the simulation. [P115]*

When there are multiple methods that could be used, a problem arises in terms of choosing the right ones and then using those in the correct manner and under the right circumstances.

> *The physicochemical properties of applied polymer thick film conductive inks can be better understood based on such investigations as thermogravimetry (TG), differential themal gravimetry (DTG), and differential thermal analysis data (DTA) – these methods should show temperature region with mass changes connected with the evaporation of the volatile part of the inks and the temperature range with polymerization process. [P138]*

Often the methods used are described too briefly or in too little detail for the reader to be able to follow what has actually been done.

> *[T]he empirical methods employed are very briefly described, as are the measures used, making the later replication by other researchers or practitioners difficult. [P151]*

This likely occurs more frequently in cases where the researcher has actively modified older methods or has had to develop completely new methods in order to obtain the appropriate design data, than in cases where the method used is already widely known and used.

The statements contained two disparate views of the role of theory in dissertation work. Viewing theoretical background as a demonstration of one’s knowledge was more common than viewing theoretical background as a basis upon which to build research. Some statements expressed both views, which also appears as a natural consequence or implication of the eclectic and polyparadigmatic use of theory. From a researcher’s perspective, this poses the challenge of ensuring that all appropriate theories and theoretical ideas have been included in the work.

8.2. The five profiles of engineering science research

The empirical analysis revealed five distinct research profiles among the fifty dissertations under study. This does not indicate that these five are the only possible types of engineering science research, nor does it suggest that all of these profiles are practised at all technical universities or institutions doing engineering science research. Also, the distribution of profiles in the field of engineering research is bound to be different for different institutions. This is due to the differences in the strength of the connection between certain profiles and substance areas (see Table 24) and the different substance profiles of different institutions.

Nevertheless, the appearance of five distinguishable research profiles supports the suggestion made by Banse and Grunwald (2009, 164-165) that although the engineering sciences share common features correlating with a specific theory-practice relationship, methodological diversity is also present. Banse and Grunwald classify this diversity into differences in methods of design, in methods of research, and in methods of implementation. The need for methodological and even philosophical diversity has been addressed for instance by Hukka et al. (2007), who argue that in a complex research area such as water management, a single approach cannot answer to all of the research needs, and that a bias in favour of a single research approach prevents the finding of adequate answers to wider governance challenges and management issues in water management.

The following sections describe the five different research profiles in more detail. They also attempt to understand the profiles in terms of the typical and possible research objectives, methodological difficulties and profiles' relation to general research philosophies and traditions.

8.2.1. Experimental design science

Experimental design science (EDS) is typically a mixture of engineering design and experimental work usually done in controlled circumstances, such as in the setting of a laboratory. The main objective of EDS is to design something, be it a machine, molecule, method, process or something else. The methodological choices do focus more on the experimental acquisition of knowledge than on the design phase, but some methodological consideration is also given to the modelling and design methods and to the preparation work done before the actual experiments.

Yet, EDS is not the kind of experimental work typically described in the natural sciences. The emphasis is not placed on explaining a phenomenon but rather on creating the circumstances that make a phenomenon appear in a certain, predefined manner. That is, the ultimate aim is not to discover, for example, certain characteristics of a material in a given situation, but instead to design both the material and circumstances to fulfil certain practical criteria, such as resistance or durability. Thus, the knowledge created is of the know-how and know-that types.

> *The initial aim of this study was to find a way toward a photopolymerizable fullerene derivative. [P10]*
>
> *This research sought to develop a directly operated on/off seat valve package, which would satisfy the requirements of digital hydraulics. [P17]*
>
> *In this dissertation the main objective has been to develop and verify the dielectric properties of new insulation materials. [P28]*

Researchers' perceptions of the function of their empirical work varies greatly, as the work often inherently entails creating knowledge, advancing a design and testing a construction in a very iterative manner. This can be suspected to be one of the major issues rendering the description of the methods and the whole inquiry process very challenging. The strengths of EDS research lie in its strongly empirical nature—the knowledge discovered directly tells us something about the real world rather than about mathematical models or theories—and it speaks to practical relevance. These "hands-on" features of EDS research are rooted in the engineering design work.

> *The research is strongly experimental, which is very important. Many of the papers which use advanced technical concepts are of the simulation-feasibility type. This work tackles "real" problems in hydraulic systems albeit in a laboratory situation. [P65]*

Alongside the challenges in explicating the entire process of inquiry come the challenges of evaluating the quality of the process and the results. Utility is the aspect of quality most easily and most often addressed and measured in EDS research. This seems natural, as the work usually clearly aims at certain practical outcomes against which the utility is evaluated. On the other hand, the more traditional quality aspects and measures of truth-value, applicability and consistency are seldom discussed and applied. This is understandable, especially if the experimental setup is constantly developing iteratively. After all, these concepts of quality have mostly been developed in the kind of experimental settings which were made for explaining rather than for creating things.

The epistemological aspects of EDS research have been discussed in the literature mainly with respect to knowledge creation in engineering in general (see e.g. Vincenti 1990). With the design science discussion mainly moving either towards a very general level (Simon, 1996) or towards specific fields such as information technology (see Hevner et al. 2004) or management (see van Aken 2004)—which do not usually employ so many experimental methods—it is difficult to find the scientific epistemological or methodological discussion with which to connect the EDS research. This can be one explanation for the absence of discussion about the conception of science, research approach and methodological framework in dissertations. Another explanation, as suggested by Hendricks et al. 2000, is that since these topics have no pragmatic consequences, they are of little interest.

The theories produced in EDS research are in Gregor's (2006) terms mainly theories for design and action. In some studies, theories for analysis or explanation are also created, but with the intention of supporting the design theories. The theories for explanation are mostly of the causal type, not of the intentional or teleological type. With respect to design-research interests (see Figure 7) in EDS, the emphasis is on material artefacts. Thus, the components of design theory (see Gregor and Jones 2007 and section 2.3.2.) most clearly present in EDS dissertations are the principles of implementation, expository instantiation and testable propositions. The first two have been labelled in the framework of information systems as research optional components of theory, which are not and do not have to be present in all the design theories (Gregor and Jones 2007). However, in EDS research, they seem to form the centre of the theory: a theory concerning the design of a material artefact cannot be justified if the material artefact is not created. Empirically testable propositions are the key to the production of new knowledge needed for design theories.

In short, experimental design science is about creating theories for design and action in order to create material artefacts. Theories are justified by creating the material artefacts partly or fully. The value of a theory is evaluated in terms of the utility of both the theory itself and the created artefacts. New knowledge for design theories is created mainly by experimental testing. Another method employed for theory creation, such as the description of the design methodology used, is of lesser importance.

8.2.2. Mathematical design science

Mathematical design science (MDS) aims at designing and creating new constructions, but unlike experimental or naturalistic design science, MDS does not directly operate within the real world but rather within the mathematical representations made by it. MDS may include some laboratory or field work, but employs mainly different modelling and design methodologies and simulation tools. The devised constructions are often mathematical representations themselves.

> *In this study, our aim was to develop a method for computing electromagnetic wave problems in spacetime.[P43]*

Despite this operation being rather abstract, the ultimate aims of MDS research are usually practical.

> *We have shown in this study that stochastic parametric modeling with powerful numerical optimization is a very accurate and robust method to quantify biomedical data. We also showed that the approach can be applied to real research problems. [P32]*

> *The objective of this thesis is to develop completely automatic 3D brain MR image analysis methods, which are able to serve the large databases based brain anatomy studies. [P36]*

The purpose of empirical work in MDS studies is rarely the pure creation of knowledge. Most often, the empirical work aims at testing a construction. Advancing a design directly through empirical work is another common goal. The MDS-research profile is also quite different from the other design profiles in this respect, as in EDS- and NDS-research profiles, the design is often accompanied by separate methods for obtaining the design data; whereas in the MDS profile, the link between empirical work and design is more direct. Thus, the sequential procedure of collecting the data and then analysing it is less commonly present in MDS studies.

Due to the design orientation and practical goals, utility is a highly valued quality aspect in MDS research, and measures of utility are applied in dissertations of this profile more often than in any other profiles. Still, also the aspects of truth-value, applicability and consistency are discussed more often in MDS dissertations than in EDS ones. This discussion relates to the "match" between the real world and the used or produced mathematical representation, which also has an effect on the practical usability of the research results.

> *Due to these approximations, there is reason to consider these results with some caution. To improve the analysis, one could calculate the bending modulus from simulations and use that value to calculate the spontaneous curvature. [P13]*
>
> *On the other hand, the reliability models are approximations of the real system behaviour. Therefore uncertainties are embedded in the reliability analysis and some extreme events may have such effects on the system that were not considered in the reliability analysis. [P27]*

Although the modelling methods used and the simulation tools and their applications are often thoroughly discussed, what is not discussed at all are the philosophical considerations. Also, the wider research approach is usually not described. In the statements, MDS dissertations were most often praised for their logic of the presentation, practical relevance and choice of methods. At the same time, most criticism was directed at the poor logic of the presentation and at the insufficient description of the methods used. This suggests that even though mathematical problem-solving is logical by nature, the transformations taking place in the building of a simulation model (see for example Krebs 2007) and the other design decisions related to the inquiry are not necessarily as logical, nor are they always even recognised (let alone explicated) by the researcher.

MDS research also chiefly produces theories for design and action supported by some theories for causal explanation. Unlike the previous profile (NDS), MDS research is primarily interested in abstract artefacts. The design theory components related to the implementation of the theories are not present in all the theories, but do exist in parts of the research. Thus, similarly to design theories in information systems, these components can also be considered merely as additional in MDS theories, as much more emphasis is placed on the principles of form and function and on the testable propositions of the algorithmic type.

To sum up, mathematical design science is about creating abstract artefacts of design theories, which can be (but need not be) instantiated as material artefacts in the course of inquiry. In the core of the created design theory lie the principles of the form and function of the created abstract artefact; i.e., the description of the new mathematical model and the modelling methods and simulation tools behind it. The system is usually justified by testing the algorithms in simulated environments, and it is considered successful if it reliably produces valid results.

8.2.3. Naturalistic design science

Naturalistic design science (NDS) combines engineering design work with field research; i.e., knowledge acquisition in real-life settings. In engineering, science fieldwork also usually engenders the human factor: the people developing, building, using or demolishing technological constructs. This often creates a connection between the research traditions more common in the humanities and social sciences than in the natural sciences. This presence of qualitative research approaches and features from the hermeneutic tradition can be seen in the greater explication of philosophical commitments and general research approach in the NDS-design profile than in the other ones.

> *Qualitative approach can be used to create a deeper understanding of the phenomenon under examination. The main goal is to understand the phenomenon more deeply to be able to develop it further. The aim is not to make large generalisations of other environments. [P46]*
>
> *This study is based on constructional science where defining a goal is important in terms of the research method [70]. Then, one does not know the result at the beginning, but knows how to get it. [P20]*
>
> *Therefore, the presented frameworks or processes that aim at improving specific aspects of organisation functioning and implemented internally in the organisation can be regarded as action research. Additionally, the research findings presented in this thesis mostly aim at improvements or finding out reasons behind specific phenomena. Therefore, the research could be characterised as Exploratory and Improving…[P25]*
>
> *Conducting totally value-free research is not possible since researcher's own ethics, assumptions and values inevitably influence at some level. However, a researcher has to believe that he/she can with objectivity, clarity and precision, report on his/her own observations of the social world including the experiences of others (Denzin & Lincoln, 2003). Especially in qualitative studies such as the present mainly is, the transparency of the research process holds an important position for reflecting the researcher's actions' and giving the reader the possibility to make their own judgments about the results. [P44]*

Interestingly, referring to design science as the conception of science behind the research or as a research approach was quite usual in NDS dissertations but almost totally absent in MDS and EDS dissertations, even when it was not linked in any way to the field studies or the human-related aspects of the study.

> *In this thesis the research approach is based on design science [Hevner et al. 2004] and case studies [Yin 2003].[P37]*
>
> *This thesis takes a design science approach to research.[P47]*

Similarly to EDS studies, the main objectives of NDS studies relate to design, but the methodological questions relate more often to the acquisition and analysis of data. The role of empirical work is most often to test a construction, but also quite frequently to create knowledge and sometimes to advance a design. This suggests that the phases of research (i.e., acquisition and analysis of data) and design may be more distinct in NDS cases than in EDS or MDS ones. In half of the NDS dissertations, the writer stated that a case method or a case study method had been used, but the understanding of the terms was very versatile. More than half of the dissertations also used some modelling/design methods.

As the general methodological guidance provided in engineering sciences is often more or less explicitly based on the philosophical considerations adopted from the natural sciences, a researcher engaged in NDS research may face methodological dilemmas, as the advice poorly matches not only his/her design activities, but also his/her research activities, which might be better understood in a framework of the humanities or social sciences. Based on the statements, the description of methods is a weak link in NDS research; in addition, research design and use of methods also received criticism.

> *During the action research project the researcher and client personnel are supposed to solve a problem together, learn from each other through cooperation and adjust continuously to new information. In this study the empirical data is collected through surveys directed to a great number of companies and interviews with many companies, and the resulting frameworks are evaluated by quite different companies.[P99]*
>
> *The research methods, constructive approach / design science and case study are introduced lightly…. The big picture of the research conducted is missing. It is difficult for the reader to follow how the research proceeded, when the case studies and the workshops were conducted, outcome of them, how long they lasted, number of participants and their role in companies. [P165]*

There has been considerable discussion about suitable criteria for scientific quality in the different research traditions (for further details, see section 2.5.1.). Perhaps due to the stronger presence of different traditions in NDS research, the discussion about different aspects of quality and the application of different quality measures is also more common in NDS dissertations than in those of the other design profiles. Like in EDS and MDS cases, utility is again the most addressed and measured aspect of quality. However, the questions of truth-value and applicability are also introduced in at least half of the NDS theses, and along with consistency, they are more regularly measured.

The theories created in NDS research mostly involve design and action, with some theories involving analysis. The research interests lie in all the elements defined by Gregor and Jones (2007): in the material artefacts, the abstract artefacts and the human understanding of both. This diversity in design research interests also appears in the diversity of the design theories created, as the emphasis between the components of design theory varies from one theory to the next. The principles of implementation are discussed rather often, but the expository instantiation is not necessarily created. The interest in the human understanding of artefacts is sometimes present in the form of reflections upon on the artefact mutability, but more often in the considerations related to implementing the theory in specific contexts and uses.

Banse and Grunwald (2009, 174) advocate research about the human understanding of artefacts, and state that since the theory-practice relationship in engineering sciences concerns both technical matters and social context, the non-technological factors must also be included in the technological reflection. NDS research is the type of design research where this is the most clearly visible and also the most strongly affected. Whether junior researchers are sufficiently well equipped for this remains open for discussion.

In a nutshell, naturalistic design science is interested in the creation of both material and abstract artefacts and also takes into account the human understanding of those. This diverse interest also makes the research diverse. NDS researchers mostly produce theories for design and action but do this by using versatile methods and emphasising components of theory quite differently, depending on the created theory. NDS theories often contain discussion on the principles of implementation, but this does not automatically lead to physical implementation of the theory. Considerations towards the human factors in technology are present, especially in the implementation principles, but also to some extent in the reflections upon the artefact mutability in different social contexts.

8.2.4. Explanatory inquiry

Explanatory inquiry (EI) bears the greatest resemblance to the traditional view of positivistic research. The conception of science is usually not explicated, nor is it cited as positivistic. The research objectives typically include to describe and to explain, the function of empirical work is to create knowledge, and the described methodology usually relates to data acquisition and analysis and sometimes to the preparation done prior to the empirical work. All the dissertations result in the know-that type of knowledge, and other kinds of contributions are rarely named.

Contrary to positivistic research, however, or at least to the espoused theory of it, all of the EI-type dissertations also state design-oriented objectives.

> *The objective in this work is to present statistically justifiable methods for characterizing the dependences between paper properties and print quality...The emphasis of the work is, however, on the probabilistic analysis of the dependences between the surface topography of paper before printing and the reflectance of the same area after printing. [P7]*
>
> *The lack of a suitable personality inventory for the current research purposes results in a sub-research objective: To develop a personality inventory that can be used to assess personalities for statistical purposes. [P50]*

Positivistic research has traditionally also been thought to contain rather strict criteria for scientific rigour and quality. These are typically addressed with measures such as internal and external validity, reliability and objectivity; yet the application of these is far from customary in EI dissertations. However, utility is not discussed as an aspect of quality, either.

Unlike in all the other profiles, the methodology seems to pose zero problems in EI, at least according to the statements. In general, the EI-research-profile-related statements contained very little criticism, and most of it was targeted at the theoretical background as a demonstration of the researcher's knowledge.

> *In my opinion what is missing is any consideration of the various techniques used to improve the mechanical properties of composites...[P92]*

In fact, methodological issues received by far the most positive remarks in the statements regarding the EI dissertations. The research process was also acknowledged quite frequently, too.

All of this seems to convey an image of straightforward research processes, in which the results speak for themselves. Reflection—whether upon philosophical issues or upon research quality—is not perceived as adding any value. In terms of a technical matrix, as presented by Hendricks et al. (2000), explanatory inquiry forms an interesting mixture of pure science and engineering science, with the objects of study and philosophical assumptions following the matrix of engineering science, theory structure and methods being more like in pure science, and values being entirely left out. In a certain respect, EI resembles the design science conception of management sciences, in which the solution created is required to be tested in order to produce a grounded technical rule (van Aken 2004) or even a formal theory (Holmström et al. 2009).

EI research mainly produces two kinds of theories: those for explanation and prediction and those for design and action. Unlike in the more clearly design-oriented profiles, the theories for explanation and prediction do not play a supporting role in the design theories. In fact, the design theories may guide the way towards theories for explanation and prediction, as the earlier quote from P50 illustrates. The EI theories created have a strong emphasis on the testable propositions and justificatory knowledge, but may also contain components related to the implementation of the theories, as the research interests contain both material and abstract artefacts (depending on the research).

In brief, explanatory inquiry resembles a positivistic view of scientific research. It is about building upon previous knowledge to find testable propositions and then subsequently testing them. Nevertheless, design research is lurking in the background, as the inquiries also contain strongly design-oriented objectives and produce theories for design and action on behalf of or to assist with the theories for explanation and prediction. Research interests may be related to either material or abstract artefacts; thus in parts of the research, the material implementation of the design theories created is also a study component. In spite of the practical goals of EI, utility is not present as an aspect of quality, as it is in the more clearly design-oriented profiles.

8.2.5. Interpretive inquiry

While explanatory inquiry somewhat resembles positivistic research, interpretive inquiry (II) shows some similarities with naturalistic or hermeneutic research. This can be seen most clearly in the objectives of II research, which are mainly to describe and to interpret. Two II dissertations also aimed at designing something and one at explaining something.

As is the case with the NDS-research profile, the empirical work done in II is field work; i.e., studies targeted directly at the real world. Thus, they also usually involve the non-technical or human aspects of technology. The methods used in II research are the methods for data acquisition and analysis, and the function of the field work is to create knowledge. All but one of the II studies referred to case methodology, but here also the use of that terminology is diverse:

> *This study uses multiple case studies during the data collection.[P21]*
>
> *The aim of this study is to build theory and test it qualitatively in case study settings. [P22]*
>
> *As a research strategy, a case study is used in many situations to contribute to our knowledge of individual, group, organisational, social, political, and related phenomena.[P44]*
>
> *The research method used under the action-analytical approach tends to be case studies due to the small number of possible research targets.[P49]*

Where NDS research primarily produced know-how knowledge, almost all of the II studies produced know-why knowledge and contributed to the socio-technical understanding and situational knowledge concerning the relationship between mankind and technologies. Know-that and know-how forms of knowledge were produced too, but to a lesser extent. Still, more than half of the II dissertations reported methods as some contributions of the research. This occurred even though the dissertations did not have any design-oriented objectives. Perhaps the methodological contributions were created as “by-products” of the knowledge and were not acknowledged as legitimate objectives of research in the beginning.

> *[Practical contributions:] Providing a methodology for assessing the customer experience.[P22]*
>
> *As a result, by providing a framework on managing a collaborative online innovation community including users’ motivations to participate, tools and methods to support participation and collaboration, and presenting important elements in the rewards strategy in collaborative online innovation communities, this study represents an important threshold for further studies. [P44]*

The epistemological and ontological issues were discussed in most of the II dissertations, and almost all of them also named or described the research approach applied. Most of the research was qualitative in nature.

> *The research methodology is action research [P14]*
>
> *This dissertation includes both quantitative and qualitative methods and fits the description of a mixed methods approach [P21]*
>
> *The main reason for choosing qualitative methodology is that qualitative research methods offer more depth and detail than quantitative methods. [P22]*
>
> *This study represents a qualitative case study with multiple cases. [P44]*

It appears as though qualitative research is a choice that needs to be justified because there has been a deviation from the “proper”; i.e.; quantitative, way of doing research.

Discussion about and evaluation of research quality is present in II dissertations in a markedly different manner from the other profiles. Although utility has some value here too, the most emphasis is placed on the traditional aspects and measures. Truth-value, applicability and consistency are addressed and assessed in all or nearly all of the studies. Also, the aspect of neutrality, which is hardly discussed at all in the other profiles, is included in the quality evaluations of II dissertations. This too could point to qualitative research as a deviation from the view of what is standard, as the conceptions of objectivity and subjectivity in qualitative research can differ greatly from the conception of objectivity in quantitative research.

It seems that although II research is in many respects much closer to the standards and processes of the traditional view of science, as research questions are formulated and answered, it is dissimilar from other research in engineering science in that much more attention is paid to explicating and justifying the ways of conducting and evaluating the research. This is undoubtedly also affected by the different research cultures in different faculties, but it is also visible in the II dissertations executed in those faculties where most of the research is something other than the II type.

Of all the research profiles presented herein, interpretive inquiry is indeed the only one which does not involve the creation of theories for design and action. The theories created in II research are theories concerning either analysis or explanation. The latter are related to the intentions of the actors and not to causal mechanisms. The research interests do not genuinely lie with the artefacts, whether material or abstract, but with the human understanding of them, either as designers or as users of technology. With no design theory produced, the analysis of the design-theory elements present is not meaningful, either.

In short, interpretive inquiry is interested in discovering the aspects of human understanding of the technological artefacts, whether material or abstract. This involves an understanding of both producers and users of technology. The theories created mainly explain something, and the explanations are of a teleological or intentional type. The absence of design objectives and the interpretive nature of the research make II somewhat different from the other profiles of engineering science research. Perhaps this is why explicating and justifying the ways of doing and evaluating the research is afforded much attention. Despite the lack of design motives, the utility of the results is considered highly important, perhaps in the hope that the people conducting the engineering design research could and would employ the results of the II research in their own work.

8.3. The philosophy of engineering science

In the year 2000, Hendricks et al. claimed that engineering science has been somewhat neglected from the viewpoint of the philosophy of science. In 2009, a major leap forward in this issue took place when *The Handbook of the Philosophy of Science* series published *Volume 9: Philosophy of Technology and Engineering Sciences,* edited by

Meijers (2009). Yet the following claim still seems to apply, at least when it comes to engineering science dissertations: the most striking point about the philosophy of engineering science in the dissertations is its absence.

Although the philosophy of engineering science is not explicitly discussed in engineering dissertations, they still convey a clear picture of the basic ideas behind scientific inquiry in engineering. Eekels (2000) suggested that proper engineering design science could be distinguished from both engineering design practice and engineering design methodics by defining engineering design science as the scientific study of the latter two. This idea gains no empirical support in this study. Instead of being research about design, the scientific inquiry in most of the dissertations included in this study appears to comprise design supported by research. It therefore seems that the demarcation problem between engineering design practice and engineering science cannot be solved by naming the former design and the latter research.

Not having a solid definition for engineering science leaves us only with the option of attempting to characterise it. Thus, the philosophy of engineering science is approached here by discussing the nature of the results and process of engineering science. The process is approached through the concept of a disciplinary matrix for engineering science, as proposed by Hendricks et al. (2000). One aspect of the disciplinary matrix, namely the values, is addressed in more detail.

8.3.1. Research outcomes in engineering science

The nature of outcomes of the engineering science inquiry work is a complicated issue, and the ways of presenting and conceptualising the results and the subsequent contributions in the dissertations are diverse. In nearly half of the dissertations, the contributions of the research were not explicitly stated. This, however, seemed to be linked to the different cultures of writing in different faculties, and does not necessarily directly indicate the difficulties in understanding the nature and the value of the appropriate results.

Examining the results described in the dissertations showed that the four types of knowledge suggested by the literature on the typologies of engineering knowledge (see Table 4) are also present in the engineering science knowledge. However, it was also noted that sometimes the distinction between know-how and know-that types of knowledge can be difficult to make. Bunge (1966) has suggested that theories in technology can be substantive or operational. Substantive technological theories provide knowledge on the objects of action, whereas operative technological theories provide knowledge on the action itself. In his view, substantive theories are derived from scientific theories, but operative theories are created by employing the method of science to the study of action. From this study of action, it is possible to derive technological rules which indicate how one should proceed in order to reach a predetermined goal. The rules can be expressed in the form "in order to attain the goal X, do Y."

In many of the dissertations, the results were expressed in the form of a technical rule ("something can be achieved by doing something in certain way"), or in a form which is transformable to such a form ("doing something a certain way results in something particular").

> *Modifying the calculation by taking into account the changes in sample geometry due to thermal expansion and pre-stretching, more exact results were achieved. [P1]*
>
> *The presented techniques result in a well performing and quite complete multicarrier communications solution. [P31]*

However, statements also of the form "something enables something" and "something can be done a certain way" were quite commonly presented as dissertation results.

> *The method enables real-time analysis of nanometer scale films. [P 10]*
>
> *A model transformation specification can be given as a system of transformational patterns. Due to the independence, transformational pattern is a suitable unit for iterative refinement of a model transformation specification. [P26]*

These discoveries cannot be transformed into technical rules, as the actual goal of the action is not present. However, the resulting knowledge pertains to the action, and is thus closer to operational than to substantive theories. Although this kind of demonstrative results surely have value to the people working with the same technologies, they pose an interesting philosophical question related to the objectives of engineering science. It has been noted earlier that both the philosophical discussions and empirical findings of this study point to the fact that striving for utility is a central feature of engineering science research. This brings about the question of whether it can be assumed that all the technological innovations have an innate utility value, and in turn the question of whether a demonstration that something can be done is sufficient evidence of the utility of the research.

In dissertations where the contributions were pointed out as such, they referred to several different matters. This is illustrated in Figure 19. Contributions were seen as methods, artefacts or declarative knowledge; and they were expressed as statements, proposals or both. In many cases, several contributions of different type were presented as a result of the dissertation work.

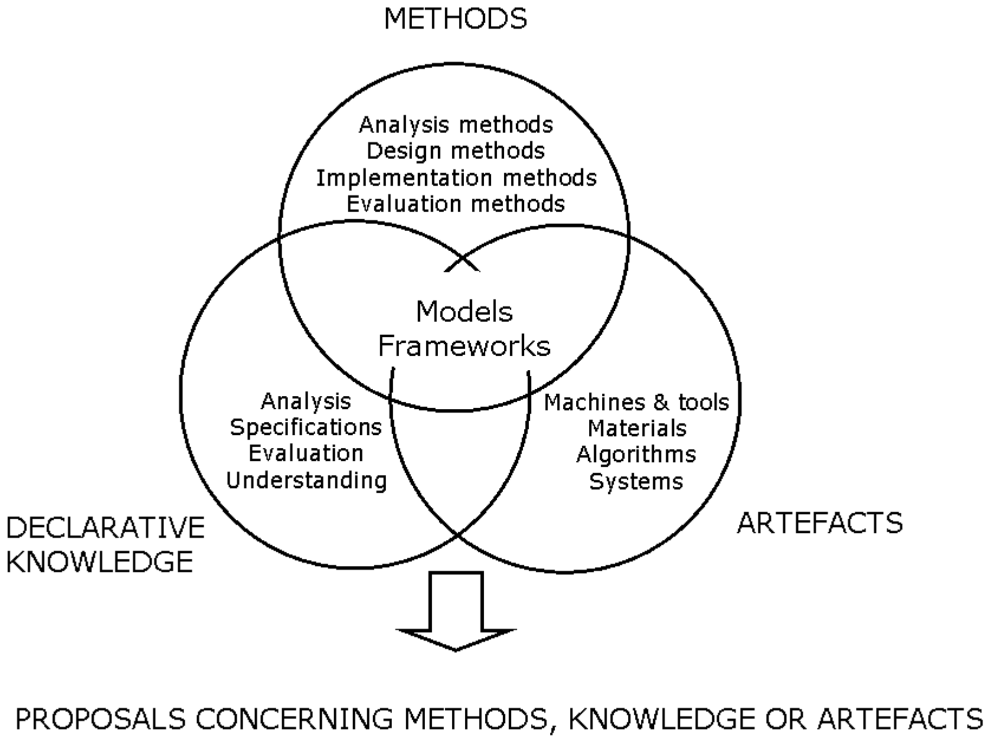


Figure 19.Categories of contributions explicated in the dissertations

The complexity of the issues lies in the different types of possible contributions, in the simultaneous presence of multiple different contribution-types, and (in some cases) in the difficulty to distinguish between the different types of results. For example, if the objective of the research is to analyse something, but the proper methods for the analysis need to be created first, the contribution of the research can be described as declarative knowledge or an analysis method or both:

> *The main contributions of this work are: ...*
> *- introduction of probabilistic analysis methods into the analysis of dependences between local properties of paper and print, and subsequent quantification of the amount of information carried by a paper property measurement on a print quality property [P7]*
>
> *To summarise the most important contributions with scientific novelty value presented in this thesis: ...*
> *• Development of methods for composing appropriate reliability worth estimates. This has included the implementation of reliability worth study (e.g. [P6]) and development methods for eliminating strategic responses so that individual deviating responses do not distort the estimates and analysis of the results ([P7]). [P27]*

Similarly, it can be challenging to draw the line between, for example, the method of implementation and the tool used in actual implementation process:

> *From the viewpoint of the less progressive companies, the development of the tools for gathering the data for interruption statistics (i.e. Interruption Manager software application) has been one contribution of this thesis. [P27]*
>
> *Summary of contributions of this Thesis are: ...*

> *- Tool development: DCS task mapper tool that is used to explore mapping algorithms themselves efficiently [P35]*

A line is also difficult to draw to distinguish between an actual artefact and knowledge about it:

> *The main contributions of this dissertation are practical solutions addressing needs of software quality improvements in selected areas of software company operations. [P25]*
>
> *[Contributions are]: ...*
> *- Proposing a modification to GNSS frame structures to allow retrieval of absolute frame timing from weak satellite signals. [P34]*

Although the differentiation between different types of contributions is probably not even in the interests of the researchers, it shows that people perceive their research tasks and hence the ideas of appropriate scientific outcomes very differently.

Another sign of the vagueness of the interpretation of the nature of engineering science research outcomes is the use of terms *model* and *framework*. Both of the words are used in dissertations disparately, and they may refer to each of the three types of contribution discussed above: methods, declarative knowledge and artefacts.

Models and frameworks as declarative knowledge:

> *Practical [contributions of the work]:*
> *Combining the constructs of customer perceived quality, satisfaction and customer experience into one model [P22]*
>
> *As a result, by providing a framework on managing a collaborative online innovation community including users' motivations to participate, tools and methods to support participation and collaboration, and presenting important elements in the rewards strategy in collaborative online innovation communities, this study represents an important threshold for further studies. [P44]*

Models and frameworks as methods:

> *The main outcomes of the research are summarised as follows:*
> *• a recommendation for common frameworks to help in adopting sustainability and eco-efficiency in strategic and operational management [P14]*
>
> *Other contributions of this research relate to two issues... A new model for the comprehensive examination of factors affecting productivity is presented. [P45]*

Models and frameworks as artefacts:

> *The main contributions of this dissertation and their key features are ...*
> *• a model for expressing human decisions so that their validity can be automatically checked after the source model has been modified [P26]*

This may be partly explained by the different subdisciplinary-specific meanings of the words, but it could also suggest that the researchers are unsure about what is the appropriate or proper way to report the contributions of the inquiry in their field or engineering sciences in general.

Another striking notion was that some of the contributions were described as theoretical in only five dissertations, and in just two dissertations, the contributions were linked to specific theories:

> *Theoretical [contributions] ...*

> *Bringing new cross-disciplinary ideas to the theory of facilities management ...*
> *Building the theory base of facilities management [P22]*
>
> *Adding the innovation management theory view to the entrepreneurial university research was the main contribution of the work. [P46]*

Thus, it seems that theories are not necessarily explicitly perceived to be the pursued results which would add value.

8.3.2. Disciplinary matrix

The comparison of technical matrices of pure science and engineering science was presented in Table 7 on page 55. It contains the characterisations about the objects of study, epistemological and ontological assumptions, theory structure, methods, values, and functions of exemplars.

Hendricks et al. (2000) describe the objects of study in engineering science as physical entities and artefacts in manmade environments. They are intentionally determined (ibid). Banse and Grunwald (2009, 156) note that the engineering sciences have a dual function in relation to the objects: firstly, technical characteristics of these objects are recorded and analysed; and secondly, new objects are anticipated and evaluated according to certain external requirements. Eekels (2000 & 2001) classifies the objects further depending on whether they relate to the action subject, action process or the action object of engineering design. This expands the area of objects from the actual physical entities to the different kinds of information about them, their construction and production processes, and their usage.

The area of objects expands even further if we accept Krebs' (2007) view that instead of real objects (i.e., physical entities) contemporary computer age science often studies mere representations of the real objects, which have undergone several transformations from real entities to mathematical entities, then to computational entities, and finally to visual representation of the computed data. In these cases, it might be more justified to state that the object of engineering science is not the actual physical entity or even information about it, but rather an abstraction or model representing it.

All of this suggests that the objects of study in engineering science are

- physical entities and artefacts;
- information about physical entities and their action processes;
- abstractions and models made of physical entities and their action processes; or
- future physical entities, information about them and their action processes or abstractions and models of them.

These were all targeted in the dissertations included in this study, with different inquiry profiles having slightly different interests (EDS- and EI-research profiles concentrating on the current and future physical entities and their construction processes; MDS-research profiles studying mainly the current and possible abstractions and models; and NDS- and II-research profiles focusing much on the human-interaction; i.e., the usage action processes).

Epistemological and ontological assumptions in engineering science are, according to Hendricks et al. (2000), only of little interest due to the lack of pragmatic consequences, and are adopted from pure science if needed. Much of this seems to hold true also in light of the empirical findings. The epistemological and ontological issues are not discussed in the dissertations in general. It is difficult to say whether the assumptions have been adopted from the pure sciences, as even this is not explicit. The implicit assumption could, however, be read between the lines that the burden of proof rests with the studies using different epistemic or ontological assumptions. However, particularly in the case of the inquiry profiles employing field work, there are also studies where the epistemic and ontological assumptions are closer to the ones of the naturalistic and hermeneutic traditions. In these dissertations, the philosophical assumptions are quite often made explicit, and even the pragmatic consequences may be discussed. Thus, this study suggests that the epistemological and ontological assumptions are

- mostly of little interest as they are perceived to have no pragmatic consequences;
- not explicated if adopted from pure science; but
- discussed and justified if they follow explicitly some other than positivistic tradition; and
- more important and more often explicit when the object of study directly includes the human interface of technological entities.

Hendricks et al. (2000) state that in engineering science, the methods are more fundamental than theory. In their view, methods are utilised to provide design data rather than to assess hypotheses; theories are used in a polyparadigmatic and eclectic manner, depending on the problem at hand. This view is supported by this study. Especially in the case of the research profiles containing strongly design-oriented objectives, the role of the theoretical background seems to be to gather enough background knowledge concerning the given design problem. Prior theoretical and empirical findings seem to hold equally important value; furthermore, the problem may be inspected in light of several different theoretical representations in order to find the approach that best serves the design and problem solving in the particular case. Theory is presented to demonstrate the candidate’s understanding of the problem—to show that s/he knows what the problem at hand is—but also to demonstrate the candidate’s knowledge about the tools available for solving the problem.

The methods used in the dissertations were rarely done so for assessing a hypothesis. In fact, in most cases, there was no theoretical hypothesis presented in the dissertation. Methods were mainly employed for design purposes in three main ways: to provide useful design data, to test a construction created in the process, and to advance a design in an iterative way (a process close to a trial-and-error method). Particularly in cases where the object of study was an abstraction, one is tempted to state that in engineering science, theory is derived from the methods.

Hence, this study suggests that in the theory structure of engineering science, the following is applicable:

- theory is adopted to problems in two ways: to provide understanding of the problem at hand and to provide knowledge of the tools usable for problem-solving;
- the theory structure is polyparadigmatic and used eclectically; and
- it usually does not provide a hypothesis to be tested.

Concerning methods, this study claims the following:

- methods are more fundamental than theory;
- methods are used in design for three purposes: to provide useful design data; to test a construction; and to advance a design iteratively, for example by providing instant feedback on the particular design solutions.

Thus, it can be concluded that with respect to the first four areas of the technical matrix of engineering science, the empirical findings of this study mainly support and further refine the proposals made by Hendricks et al. (2000).

8.3.3. Values and norms

When Airila and Pekkanen (2002) provide guidelines for dissertation work in the engineering sciences, they refer to the characteristics of science such as objectivity, progression and publicity; characteristics of scientific research, such as publicity, criticality and autonomy; and characteristics of scientific knowledge, such as publicity, truthfulness, law-likeness and generality. The views of Airila and Pekkanen can be most easily understood in light of CUDOS norms and the positivistic view about quality of research. Thus, they also reflect the epistemic and ontological assumptions of pure natural science and for their part support the claim made by Hendricks et al. (2000) that these assumptions in engineering science derive from pure science, at least at the level of the espoused theories.

Hendricks et al. (2000) suggest that values in pure science are explicitly justified, with truth being important; whereas in engineering science, the justification of values in implicit, the focus is on efficiency and practical usefulness, and the conception of truth is pragmatic. Therefore, the views of Airila and Pekkanen (2002) and of Hendricks et al. (2000) appear to be contradictory. One possible explanation for the contradiction is to consider Airila and Pekkanen’s view as representative of the espoused theory concerning the values in engineering science, and to comprehend Hendricks et al.’s view as representative of a theory of practice concerning the same values.

It was hoped that the empirical findings from this study would shine light onto the theory of the practice of engineering science. Hence, these findings were expected to be and actually are more in line with the ideas from Hendricks et al. The justification of values in engineering science dissertations was definitely more implicit than explicit.

When the quality and value of the work were evaluated, this was most often done with respect to the practical utility of the work and results. Utility was measured against concepts such as competitiveness, cost-effectiveness, practical potential, usefulness and viability. Utility was measured in more than half of the dissertations, but truth-value was assessed in only approximately one-fifth of them. This could also be interpreted as a sign of a pragmatic concept of truth: if an idea works well enough, it is sufficiently true. Naturally, there was some divergence also in the values and quality aspects in accordance with the research profiles, with the emphasis on utility being stronger in design-oriented profiles than in research-oriented ones. Still, the emphasis on truth-value does not follow the opposite path, as it is addressed the most in naturalistic or field-oriented profiles, whether design or research focused.

Another interesting contradiction relating to values and norms can be seen when the positive comments from the statements are compared to the grades awarded. Empirical research, whether experimental or field based, received most of the expressions of praise in the statements of most profiles, yet thesis work based on mathematical simulations were most often awarded the grade “passed with distinction.” This could be interpreted as the espoused theory valuing the hands-on work done in real-life or authentic situations, but the theory of practice genuinely valuing the use of mathematical abstractions and quantitative methods. Soerensen (2009, 96) has expressed the following idea concerning the role of social sciences in engineering:

> *It seems more probable to assume that if engineers really used knowledge gained from social science, this fact would tend to be rendered invisible in their accounts of developing new technologies because the social sciences are less prestigious than natural science. Social science contributions might consequently become prone to being overlooked or hidden because acknowledging the value of social science input might ultimately damage reputations. Such acknowledgement might even be thought to endanger the scientific status on engineering. (Soerensen 2009, 96)*

The prestige of natural science also offers an explanation here, with the quantitative and mathematical methods typical of natural science being more compliant with both “good science” and the espoused theory of the scientific quality of engineering science. However, a closer examination of the dissertations awarded the grade “passed with distinction” reveals that addressing and measuring the quality aspects of truth-value, applicability or generalisability is rarer in these distinguished dissertations than in others. This forms a very interesting picture of what in the engineering sciences is considered to be exceptionally good research. It also raises the question of how aware engineering scientists are of the values and ideals truly underpinning the research practice.

8.4. Summary

This chapter has presented the empirical research findings of this study. It began by concluding that discussing the term *engineering science* as a singular noun is meaningful. This study supports the view that the different engineering disciplines have sufficiently similar lines of knowledge production, at least with respect to the objectives, results, norms, quality criteria and challenges related to the research.

The majority of the dissertation research performed in the different engineering sciences seems to suit the characterisation of design science. Most of the dissertations studied held objectives such as to construct, to evaluate, to improve or to demonstrate; and even the dissertations aiming at explaining causalities also usually contained design-oriented objectives. However, the design orientation is less evident upon examination of the methodology: only little over half of the dissertations reported the usage of systematic methods for modelling or designing a construction. Instead, methods for data acquisition or data analysis were more frequently described. This suggests that the basic ideas of design science should be introduced to engineering science researchers.

The results indicate that utility is a relevant norm for engineering scientists. In the dissertations, it was by far the most discussed aspect and most used measure of quality. Otherwise, the question “How can one assess the quality of engineering science research?” seemed to have no clear answers. In fact, it is not even clear if the quality *should* be assessed. Although contemporary measures such as reliability and validity work in some profiles, the majority of the research does not find those applicable. Still, there seems to be nothing available that could be offered to replace the quality tools adopted from other sciences, either.

Hendricks et al. (2000) state that in engineering science, methods are more fundamental than theory, the use of theory is eclectical and polyparadigmatic, and methods are used in order to provide useful design data rather than to assess a hypothesis. Judging from the statements comprising part of the data, the biggest challenges related to the dissertation research pertain to the description of methods, the theoretical background and the logic of the presentation of the research. This is rather understandable, if the theoretical background does not guide the selection and use of methods, and the methods for obtaining the data evolve alongside the iteratively developed design.

The empirical analysis revealed five distinct research profiles among the fifty studied dissertations. **Experimental design science** deals with creation of theories for design and action in order to create material artefacts. New knowledge for the design theories is created mainly by experimental testing. **Mathematical design science** concerns the creation of abstract artefacts of design theories, which can be, but need not be, instantiated as material artefacts in the course of inquiry. The system is usually justified by testing the algorithms in simulated environments, and it is considered successful if it reliably produces valid results. **Naturalistic design science** is interested in the creation of both material and abstract artefacts, and also takes into account the human understanding of them. It produces mostly theories for design and action, and considerations towards the human factors in technology are present in the implementation principles and to some extent in the reflection upon the artefact mutability in different social contexts. **Explanatory inquiry** is about building upon previous knowledge to first find testable propositions and to subsequently test them. Nevertheless, the inquiries also have strongly design-oriented objectives and produce theories for design and action on behalf of or to assist with theories for explanation and prediction. In spite of the presence of practical goals, utility is absent as an aspect of quality, as opposed to the more clearly design-oriented profiles. **Interpretive inquiry** concerns the discovery of aspects of human understanding about the technological artefacts, whether material or abstract. The theories created are mainly for the sake of explanation, and the explanations are of a teleological or intentional type. The absence of design objectives and the interpretive nature of the research render it distinct from the rest of engineering science research; however, the utility of the results is considered highly important.

Although the philosophy of engineering science is not explicitly discussed in engineering dissertations, they still convey a clear picture about the basic ideas behind scientific inquiry in engineering. The scientific inquiry in most of the dissertations included in this study appears to be design supported by research. It also seems that the theories are not necessarily explicitly perceived to be the pursued results of inquiry.

Hendricks et al. (2000) have proposed a technical matrix that combines some central elements of the philosophy of engineering science. The empirical findings of this study mainly support and further refine their suggestions with respect to most areas of the technical matrix of engineering science. The justification of values in the engineering science dissertations was decisively more implicit than explicit. When the quality and value of the work was evaluated, it was most often done with respect to practical utility. This could be interpreted as a sign of a pragmatic concept of truth: if an idea works well enough, it is sufficiently true.

These interpretations of the empirical data have been influenced by previous theories and by philosophical discussions around the subject. However, deeper reflection upon the findings in light of previous knowledge and with respect to the research questions will be presented in the next chapter, and the theoretical and practical conclusions will be drawn in the final chapter. The final chapter will also address the quality of this study and present some suggestions for further research.

9. Discussion

> *Since engineers tend not to be introspective, however, and the philosophers and historians (with certain exceptions) have been limited in their technical expertise, the character of engineering knowledge as an epistemological species is only now being examined in detail. This book is a contribution to that effort. (Vincenti 1990, 3)*

Since engineering scientists tend not to be introspective, either, the character of engineering science knowledge and the processes related to its creation are only now being empirically examined in detail. This dissertation is a contribution to that effort.

The research question to be answered was: **What is engineering science like as a scientific discipline?** The question was approached with the help of three subsidiary research questions:

I. What are the essential features of engineering science?

II. What kind of philosophy of science does engineering science entail?

III. What sort of challenges does engineering science pose for junior researchers?

The phenomenon was studied in the context of Finland in the form of single-case study, with Tampere University of Technology as the case setting. The transferability of the results across institutions and into other contexts is discussed in detail in section 10.3.2.

Engineering science as a scientific discipline could be described in a nutshell as follows. This study corroborates the idea of Hendricks et al. (2000) that engineering science is most certainly a scientific discipline in and of its own, and is characterised by its own technical matrix. It cannot be regarded as a mere part of natural science, nor can it be wholly classified as an applied science, as natural science knowledge is only some of the knowledge applied in engineering science research.

If engineering science is understood broadly, as in this study, it cannot be defined as research about engineering design, as Eekels (2000&2001) has proposed. Most of the inquiries presented in the 50 dissertations can be classified as design science, with objectives similar to those of engineering design. This suggests that a demarcation between engineering practice and engineering science cannot be made by calling the former an act of design and the latter an act of research. Drawing the line is much more difficult, but it might be done based on the generality of the design solution and on the level of abstraction of the knowledge used and produced: engineering practice is about solving one problem at a time; engineering science is about simultaneous solving a set of problems.

Kroes (2009a) understands engineering science as research studying whether a given construction fulfils a certain pre-defined criteria, and places the acts of design under the heading “engineering design.” Selecting this kind of definition for engineering science and engineering design solves the demarcation problem. However, it leads to the problem of what to call the activity and results of inquiry which have been done in the field of engineering, have been published in scientific publications, and have yielded, for example, doctoral degrees. In this study, this has been called engineering science, and it has now been noted to consist mainly of design activities. Despite the question mark in the use of terminology, it is important to acknowledge that design activities are also central to engineering inquiry of the highest level.

Engineering science is a discipline having considerable diversity. The objectives, methods, empirical processes and results related to one type of inquiry can be very different from other types of investigation. This study found five distinct research profiles, but there may well be more to discover.

At the moment, engineering science is a discipline lacking discussion about its philosophical grounds, as noted by many (see e.g. Meijers 2009, Hendricks et al. 2000, Ahern et al. 2012). The philosophy of engineering science has not been of particular interest, as it appears not to have many direct consequences. Yet, there are challenges that engineering scientists meet that may well be rooted in the lack of common understanding about the epistemic, ontological and methodological issues.

The following sections elaborate on the description further through answering the subsidiary research questions. In addition to the theoretical objectives, the inquiry also has had the more practical objective of evaluating the role and success of doctoral education in engineering science in Finland, with respect to the development of the scientific thinking of doctoral candidates. The discussion concludes by addressing this question.

9.1. Essential features of engineering science

Engineering science features both convergence and divergence. Mitcham and Schatzberg (2009, 42) view that it is legitimate to use the noun in either the singular or in plural. Both convergence and divergence have also presented themselves during this study. Banse and Grunwald (2009, 160) characterise the specific nature of engineering science as having three characteristics: the engineering sciences 1) are target-oriented; 2) are constructive in nature; and 3) integrate knowledge from natural sciences, other technical sciences and social sciences. This also emerges well in this study, which has pointed out the strong design orientation and utility as a norm shared in common by the engineering science research. The design orientation reflects the constructive nature, whereas the utility norm reflects the target orientation of the field.

Eekel’s (2000) idea of defining engineering science as the scientific study of engineering design practice and engineering design methodics does not seem to work as a basis for demarcation between engineering science and engineering. Bucciarelli's (2013) view of engineering science being more akin to the natural sciences than to engineering practices was based on sociological rather than philosophical viewpoints (degree requirements, social organisation of work) and is not empirically supported, either. From a philosophical viewpoint, it seems that the line of demarcation between natural science and engineering science is more easily made than between engineering science and engineering practice. As predominantly constructive activities, the processes of engineering science and engineering are much alike, but the former likely aims more at finding general solutions and the latter at finding particular solutions to technological problems.

The feature of divergence shows in the different research profiles identified in the data. The different profiles have diverse needs concerning the integration of knowledge and methods from other disciplines into engineering science research. The characteristics of the different profiles are presented in Table 30.

Table 30. Characteristics of the engineering science research profiles discovered in the study

	Experimental Design Science	**Mathematical Design Science**	**Naturalistic Design Science**	**Explanatory Inquiry**	**Interpretive Inquiry**
Research interest	Material artefacts	Abstract artefacts	Material artefacts Abstract artefacts Human understanding of technological artefacts	Material artefacts Abstract artefacts	Human understanding of technological artefacts
Objective of inquiry	To design	To design	To design and describe	To design and explain	To describe and interpret
Empirical work	Laboratory work Creating knowledge, testing constructions, advancing design	Simulation Testing constructions, advancing design	Field research Testing constructions, creating knowledge, advancing design	Laboratory work Creating knowledge	Field research Creating knowledge
Results	Know-how and know-that	Know-that and know-how Artefacts and methods	Know-how Methods	Know-that Methods	Know-why and know-that Methods
Resulting theory	Theory for design and action Theory for explanation (causal) Theory for analysis	Theory for design and action Theory for explanation (causal)	Theory for design and action Theory for analysis	Theory for explanation and prediction Theory for design and action	Theory for explanation (intentional)
Evaluation of quality	Utility is discussed and measured	Utility is discussed and measured	Utility, truth-value and applicability are discussed Utility measured	Consistency is discussed	Truth-value, consistency, applicability, neutrality and utility are discussed and measured
Research philosophy	Not mentioned	Not mentioned	Somewhat discussed	Not mentioned	Discussed

The explanatory inquiry type is closest to the positivistic view of natural science research, but EI inquiries also strongly contain design-oriented objectives. Interpretive inquiries have no design objectives and are in many ways similar to interpretive studies in the social sciences or humanities, but with the research targeted towards technological artefacts. Naturalistic design science shares some common ground with design science-oriented management research, as described by van Aken (2004), and both experimental and mathematical design science partially resemble design science in the information systems research, as described by Hevner et al. (2004), but not in a completely similar manner.

The profiles do not follow the organisational boundaries of faculties and do not seem to represent particular subdisciplines, either. However, the connection between some profiles and faculties is stronger in some cases than in others. This is to be expected, as the organisational culture of different departments directs the perception of valid targets, objectives and methods of inquiry to some extent (Ylijoki 1998). Still, the presence of dissertations from almost all of the faculties in almost all of the profiles indicates that diverse approaches to inquiry are appropriate and applicable, regardless of the subdiscipline of engineering science. Moreover, these diverse approaches are required to find adequate answers to complex technological problems (Hukka et al. 2007).

9.2. The philosophy of engineering science

Table 31 presents the technical matrix of engineering science by Hendricks et al. (2000), modified with the inclusion of the results from this study. The concept of the technical matrix has its roots in Thomas Kuhn’s (1996) idea of the disciplinary matrix, which he also describes as a “constellation of group commitments” (ibid, 181).

The theory structure in the technical matrix refers to the way in which earlier knowledge and theories are incorporated into the research. Gregor and Jones (2007) use a similar term to describe the components that are, or should be, present in information systems design theory. However, using their analysis of the anatomy of design theory reveals that the products of engineering science research are rather diverse in nature.

Although engineering science research may predominantly be classified as design science research, it also contains inquiries which are closer to explanatory or interpretive research. However, even when the inquiry itself does not produce theories for design and action as its end product, it may contain design theories as sub-objectives of the research (e.g., research and validation of a research method), or it may discuss the ways in which the research results can be practically implemented in future design research by other people.

Some design science research in engineering science is interested in material artefacts, some in abstract artefacts and some in both. Depending on the type of interest, the emphasis on the design theory lies either in 1) the components related to the practical implementation of design theories, 2) the form and function of the theories, or

3) the testable propositions included in the theories. Thus, the components that form the information systems-design research viewpoint are labelled additional, and really seem to virtually be the core elements in certain types of engineering science design research, but merely additional elements in other types. The human understanding of artefacts, which relates to Ihde's (1997) knowledge through technologies, has a strong presence in some engineering science design theories but plays practically no role in others. Similarly, the role of justificatory knowledge varies from theory to theory.

Table 31. A technical matrix for engineering science, based on the ideas of Hendricks et al. and modified with the understanding gained in this study (original parts bolded)

	Engineering science
Objects of study	Objects include **physical entities and artefacts;** information about physical entities and their action processes; abstractions and models made of physical entities and their action processes; or future physical entities, information about them and their action processes or abstractions and models made of them.
Epistemic and ontological assumptions	Mostly of little interest as these assumptions are perceived to have no pragmatic consequences; not explicated if **adopted from pure science**; but discussed and justified if they follow some tradition other than the positivistic one; and the assumptions are more important and more often explicit when the object of study directly includes the human interface of technological entities.
Theory structure	**Theory [is] adopted to problems** in two ways: to provide understanding of the problem at hand and to provide knowledge of the tools usable for problem-solving; is **polyparadigmatic and used eclectically**; and usually does not provide a hypothesis to be tested.
Methods	**Methods are more fundamental than theory**, and methods are used in design to provide useful design data; test a construction; and advance a design iteratively by, for example, providing instant feedback on the specific design solutions.
Results	Contributions are material or immaterial artefacts, methods, declarative knowledge and combinations of these; results are rarely perceived as theoretical or as theory of any kind; they contain technical rules but are expressed as statements; and they simultaneously entail several knowledge types.
Values	**Implicit justification** (if any); **Efficiency and practical usefulness**: utility as the most important norm; **Pragmatic concept of truth;** and Quantitative research is valued over qualitative research.

It seems fair to say that there is no uniform set of contributions that engineering science is pursuing, nor is there a standard type or form of knowledge which results from scientific inquiry in engineering science. The different knowledge types that have been identified in engineering practice (McGormick 1007, Ahmed at al. 2005 for Venselaar 1987, de Vries 2005, Ropohl 1997, Vincenti 1990) are also largely present in engineering science. Like engineering, engineering science consists of multifaceted problem-solving, which often requires 1) building both conceptual and material constructs and 2) employing activities of both research and design, resulting in both specific and general knowledge of different knowledge types.

It could consequently be concluded that engineering science research produces different types of theories, most of which entail direct design objectives, and the rest of which indirectly aim at advancing engineering design knowledge. Yet, these are rarely presented as theories, but rather as statements, which in most cases can be transformed into technical rules for action (as proposed by Bunge (1966)). The theory structure of engineering design theory, now referring to the components of design theory, is not as uniform as in information systems design theory (as suggested by Gregor and Jones (2007)). Instead, it emphasises different components, depending on whether the research interests are focused on the material artefacts, the abstract artefacts, or the human understanding of the technological artefacts and theories.

9.3. Challenges in engineering science research

This study revealed a number of practical challenges facing researchers in engineering science. The description of methods, construction of a comprehensive theoretical background and presentation of research in a logical manner were identified as the major targets of criticism in the statements written about the dissertations. The description of methods appeared to be more challenging in the dissertations linked to design-oriented profiles than to inquiry-oriented ones. The role of the theoretical background in the dissertations was perceived differently depending on the associated research profile. The statements linked to dissertations of experimental design science, mathematical design science or explanatory inquiry profiles emphasised the role of theory as a demonstration of knowledge; those linked to dissertations of the interpretive inquiry profile emphasised the role of theory in building the research framework; and those linked to dissertations of the naturalistic design science profile addressed both functions rather evenly.

The areas of challenge identified do not come as a surprise. Finnish doctoral students in engineering science assessed earlier the development of their research skills as being weaker than those of doctoral students in the humanities or social sciences. They also perceived methodological and theoretical supervision as being weak. Only forty-two percent of them reported receiving as much supervision as they would have needed, and about thirteen percent had received no supervision at all. (Hiltunen & Pasanen 2006).

There also exists, however, a set of challenges on a completely different level. These challenges stem from the contradictions between the espoused theory and (the actual) theory of practice of engineering science research. This study suggests that there are two contradictions of this kind: one related to the quality attributes of research and the other to the objects of research. In the theoretical discussions concerning engineering science, research quality is frequently addressed with use of the attributes or aspects adopted from pure science: truth-likeness, applicability, consistency and neutrality (see e.g. Airila & Pekkanen 2002). In philosophical discussion, the sufficiency of truth as a justified true belief has been questioned (see e.g. Meijers & de Vries 2013), and the need for criteria related to practical relevance is noted (see e.g. Niiniluoto 1985 and Hendricks et al. 2000), but these have not been operationalised in terms of research. In real life, contemporary quality attributes are quite rarely discussed, let alone measured. Instead, the utility of the research findings is regularly assessed through different means. This leaves the researchers with significant uncertainty about the appropriate approach towards the evaluation of research quality in engineering science.

Another difference between what is stated and what is actually done concerns the objects of research. On the one hand, it is often stated in the statements that it is especially valuable that phenomena are studied in real-life settings or with hands-on experiments. On the other hand, it is the numeric simulation studies that most often receive the highest grade awarded for the dissertations. Based on this, it is difficult to judge whether it is better to study real-life objects or their abstractions, or whether the study of both is equally important.

9.4. Doctoral education as the facilitator of developing scientific capabilities

Chapter Four introduced the basic process of doctoral education in the engineering sciences in Finland and also presented certain identified challenges. Among the challenges experienced by the doctoral students were the lack of methodological and theoretical supervision and the lack of constructive criticism (Hiltunen & Pasanen 2006). Based on a small interview study, Peltonen (2005) suggested that the three areas of challenge in doctoral studies are the selection and use of research methods, publishing, and internalisation of the mode of scientific thinking. The difficulties in the first area, choice and use of research methods, were related to 1) an inability to separate methods from the substance, 2) emphasising the technical use of methods and overlooking their epistemological limitations or 3) difficulties with matching suitable methods with the research objectives. The challenges in the second area, publishing, pertained to difficulties in producing text and argumentation. Finally, the challenges in the third area, scientific thinking, were linked to four matters: 1) setting interesting research questions, 2) relating to other people’s work, 3) understanding the other people’s research processes, and 4) adopting a critical attitude.

The research-related challenges identified in this study are much in line with earlier findings, and they also go hand in hand with the areas where supervision is felt to be insufficient. Choosing and using research methods; rooting one’s work in theories and earlier research; and describing all this in a logical manner, all the while explicitly justifying the choices made during research, are all difficult issues for doctoral candidates. The perception of poor supervision in the same areas suggests that the explication of these issues may also be difficult for more experienced researchers.

Lahenius and Martinsuo (2011) observed that part-time doctoral students especially had difficulties with starting to think in a scientific way. This can indicate that at the moment, scientific thinking skills develop through indoctrination into the community culture instead of through explicit teaching or supervision. Thus, it seems as though the whole discipline is somewhat lacking a language or even vocabulary for talking about the methodological and theoretical issues of engineering research. A similar lack of language was noticed by Ahern et al. (2012), who discovered that engineering academics experienced more difficulties in verbalising what critical thinking meant than did academics from non-technical fields. This is all understandable, given that much of the field's espoused theories concerning these matters come from the natural sciences, but the theories is action are predominantly those of design science. The language has not evolved because the epistemological issues have not been discussed and taught.

The reasons hindering the development of critical thinking of doctoral candidates and diminishing the constructive criticism by the supervisors are much the same as those cited above. Being constructively critical is difficult if the grounds for evaluation are not common knowledge. As many of the traditional research-related quality aspects are not directly applicable to design science-research type of activities, and as no new ones are systematically being introduced, the field truly is missing the appropriate measures and tools for evaluating the quality of research. With the practical approval of many of the research results coming from industry's adoption of the developed solutions, the scientific discussion of quality may even seem unnecessary.

According to Christensen and Ernø-Kjølhede (2008), this lack of metadiscourse extends to the sociological, historical, ethical and pedagogical perspectives of engineering culture. From the point of view of advancing knowledge in engineering science, developing the language and discussing the different perspectives of the scholarship of engineering science is also crucial, as the renewal and regeneration of the discipline depends on researchers' having sufficient skills for self-reflection, interdisciplinary co-operation and adjustment to changing conditions (ibid.).

10. Conclusions, implications and evaluation

> *The rules of scientific investigation to which we have been referring are not those common to research methodology nor are they the rules for socially approved presentation of research findings to the scholarly community. They are the rules generated in interaction to guide further investigation in a manner likely to be scientifically fruitful. As the rules of the painting by numbers kit relate to the artistic creation, so do sets of research procedures relate to the successful scientific investigation. (Gherardi & Turner 2002, 86)*

The objective of this study was to gain an understanding of the philosophy of engineering science in Finland so as to help advance the discussion within the discipline, across disciplines and with society at large through providing a framework and vocabulary for philosophical and methodological discussions. It was also hoped to enhance doctoral education by introducing better possibilities for systematic training on the philosophical, theoretical and methodological issues; and by promoting better supervision.

The purpose of this final chapter is to clarify the meaning of the results and to show how they can be used to improve the actions of the engineering science community in Finland. This is done by first presenting four theoretical claims based on this study, and then by introducing some practical ways to employ or overcome these claims in doctoral education and research. Therefore, the dissertation aims at offering both a theoretical and a practical contribution to the scientific community. The quality of the research is discussed through the questions of truth-value, applicability, consistency, neutrality, publicity and novelty. Finally, some suggestions regarding future research needs in this area are extended.

10.1. Theoretical claims

1. **Engineering science is a scientific discipline in and of its own. The conception of science behind it is predominately design science, albeit this is not explicated in research.**

The debate concerning the independence of engineering science as a scientific discipline has historically been about the relationship between engineering science and natural science. Hendricks et al. (2000) have provided a philosophical analysis about the research profiles in pure (natural) science, applied science and engineering science. They came to the conclusion that engineering science features its own methodology and creates its own body of knowledge. This empirical study confirms these conclusions and takes the stand that engineering science does not belong to the realm of natural sciences, pure or applied, but is a scientific enterprise of its own kind, with its own research problems, objectives, methodological and theoretical frameworks, and standards of scientific quality.

The conception of science behind much of the research done in engineering science is that of design science. Almost all of the dissertations held design-related objectives, and utility was the quality aspect most commonly referred to. This relationship between engineering science and design science has been suggested earlier, but from another angle; i.e., by naming the engineering science as a typical example of design science (see e.g. Simon 1996). However, the term is not employed in engineering science dissertations, with the exception of some computer engineering- and industrial management-related works of research. Thus, the methodological framework most often suitable for dissertations could have been adopted from the literature concerning design science, had this been acknowledged by the doctoral candidates. Instead, usually no explicit framework was implemented, and a better description of methods and more logical presentation of work were required in the statements.

2. **Engineering science is a discipline with considerable diversity. All of this diversity is not due to subdisciplinary differences, but rather to the distinct research profiles needed to address different types of research problems.**

Engineering science is a large discipline having many subdisciplines under its umbrella. The differences between the subdisciplines are in this study reflected in the differences between the five faculties. Some of the differences, however, seem to be linked to the type of problem at hand. These differences appear in the discovery of the five distinct research profiles. The profiles are not mutually exclusive, nor can they be expected to fully cover the entire realm of engineering science. Therefore, they cannot serve as a taxonomy (Gregor 2006).

Nevertheless, the profiles demonstrate that similar problems across the subdisciplines are approached in a similar manner. They also show that there can be several different views on what is considered to be good and valid research, even within a subdiscipline of engineering, and that these should be accepted rather than restricted, as feared by Hukka et al. (2007). Acknowledging the differences between the profiles can help in the adoption of a paradigm, if a doctoral candidate is presented with several different exemplars related to the paradigm, instead of being offered just one that does not suit the type of research problem s/he wants to solve.

3. **Scientific inquiry into engineering knowledge does not pursue a standard form of knowledge, such as a theory or proved or disproved hypothesis. Like engineering, engineering science entails multifaceted problem-solving, which results in both particular and general knowledge of different knowledge types.**

As multifaceted problem-solving, scientific inquiry into engineering science often requires building conceptual—but also material—constructs and developing new methods for different purposes (analyses, design, implementation, evaluation). Consequently, the contributions recognised in research are of many kinds: artefacts;

methods; declarative knowledge of different sorts; or proposals concerning the usage of the created artefacts, methods or knowledge.

As a form of knowledge, proposals can be considered as being technical norms or rules, as described by Bunge (1966). However, not every piece of research results in explicit, or even implicit, proposals. Thus, it cannot be stated that engineering science research always results in knowledge in the form of technical norms. Arriving at novel theories or at new knowledge extending or otherwise linking to existing theories seems to be even rarer than arriving at technical norms.

One interesting group of inquiries are the works of research which result in demonstrations of technical feasibility. The inquiries do not result in proposals, as there seems to be no other objective than to show that something can be done in certain way. This kind of research for alternatives to contemporary technologies likely aims at gaining practical benefits such as cost reductions, greater environmental friendliness and better user experience; but this is expressed neither in the objectives nor as contributions. In these cases, engineering science is certainly not about something being true, and is not even so much about something being useful, but rather about something being possible.

4. **Problems related to describing the methods used, building a comprehensive theoretical background and presenting the research in a logical manner are common. Additionally, the contradictions between the espoused theory and theory of practice of engineering science research can pose a challenge for junior researchers and doctoral education.**

Scrutiny of the pre-examiners' and opponents' statements of the dissertations revealed that problems related to describing the methods, grounding the research in theory and presenting the research in a logical manner are common. Interestingly, these are the same areas—methodological and theoretical supervision and constructive criticism—where engineering students' experiences of the thesis supervision were significantly worse than the experiences of students from all other disciplines. This suggests either that not enough advice is provided regarding these matters, or that the advice given is, for some reason, not taken into account.

As little is written about conducting research in engineering science, both doctoral candidates and their supervisors are likely to look for help from other disciplines, such as the natural sciences. Also, the courses and guides directed towards engineering doctoral students often have a strong natural science flavour to them (see e.g. Airila & Pekkanen 2002). Thus, the espoused theory of engineering science research; that is, what it is said to be like, becomes easily very different from the theory of practice; that is, what the engineering science research actually is like. A situation like this is likely to cause confusion, which most probably does not help to advance the research.

A similar source of confusion was discovered in the contradiction between what was valued in statements and what was valued in grades. In the statements, the importance of doing research in the natural environment was emphasised, yet the dissertations rewarded with distinction were typically based on a mathematical simulation that was disconnected from the natural environment of the phenomena studied.

10.2. Practical implications

The theoretical discoveries and the created explicit mental model of the philosophy of engineering science in Finland do not automatically lead to more intelligent action. In order for this study to have any effects on the three realms of universities; i.e., education, research and societal interaction, the findings must be accompanied by practical suggestions for improved action. Five such suggestions follow.

1. **Build systematic training involving the philosophy of engineering science and engineering science methodology for all doctoral students**

Virtually all of the degree structures for doctoral degrees in engineering at Finnish universities entail some general studies, whose contents include research methodology and ethics, philosophy of science and academic writing (see Table 10). The extent and content of these studies vary among universities. It is also typical for students to have a rather large freedom of choice of the courses and literature included in their degrees. Although there are multiple benefits to this kind of flexibility, it may also lead to a situation where doctoral students choose specialised subject courses at the expense of general training and thus avoid any contact with these issues.

Some universities or faculties have a strongly recommended or compulsory introductory course for all doctoral students. This could be a good option, provided that the course provides a systematic and coherent approach to the topics and is based on a shared mental model of engineering science research. If this is not the case, the course may end up being more confusing than clarifying, and may perhaps even convey ideas of engineering science which are too limited or restricted.

The training may naturally also come in the form of supervision instead of courses. However, in this case as well, the objectives and the mental model of the training should be explicated in order to be systematic. In the best case scenario, both the curriculum and supervision of the doctoral studies provide systematic support for the development of the doctoral student's personal view of engineering science.

2. **Introduce the concept of design science and the ideas of the different research profiles as part of the systematic training**

This study suggests that more engineering science researchers could benefit from knowing more about the concept and idea of design science than currently do. Particularly for those researchers having design-oriented objectives, design science can provide an explicit framework for conducting and evaluating the inquiry. This is expected to be a useful aid for doing research, even if the ideas have to be adopted from outside of one's actual area of expertise. In the engineering context, many of the issues of design science are discussed under the heading of engineering design (see e.g. Kroes 2009a). It would also of benefit to students if these ideas were included in training.

Acknowledging that there are different profiles in engineering science research is also suspected to be a useful insight for all researchers. Especially in cases where one's own research is somewhat different from the mainstream research in the subject area, the idea behind the profiles could offer the researcher something to grasp when designing, conducting and defending his/her research. It also offers opportunities to look for solutions and help across subdisciplinary boundaries.

As in the first practical suggestion, here too systematic training is understood as an appropriate combination of course-based training and supervision. One possibility is to include the general introduction of topics in the introductory or methodology courses, and then to deepen insight into needed areas through supervision.

3. Arrange opportunities for supervisors to discuss philosophical and methodological issues

Increasing and improving supervision in philosophical and methodological issues requires giving more support to the supervisors in relation to the issues themselves. As the supervisors are already experts in scientific research, a good option is a peer support approach, where experts learn from each other through professional discussion. Although this could in theory take place during coffee breaks, considering the contemporary academic pace, that is not likely to happen, as these are that kind of issues that require a certain amount of time and concentration to be dealt with. Therefore, reserving a special time and place for the discussions is expected to be beneficial.

As noted earlier, the language around the philosophy of engineering science is in development stages and is still partially lacking or at best incomplete. This can complicate the commencement of discussion. To facilitate the beginning, the first discussions within the community could be moderated by an outsider. The role of the facilitator would be to steer the discussion in a manner that brings all the knowledge and viewpoints of different experts to the table. Unlike a chairperson, the facilitator is an outsider, is neutral in terms of the topic, and brings no personal opinions to the discussion. (Nummi 2007.)

4. Collect a pool of methodological supervisors for different research profiles

This study has demonstrated the existence of five different research profiles which are somewhat uniform across the different faculties. Although there were at least three different profiles present in all the faculties, and all five profiles were represented in the two largest ones (see Table 24 for details of the profile-faculty distribution), depending on the faculty, a certain profile or profiles seem(s) to be more common than the others. In this situation, acquiring methodological advice appropriate to the research profile is likely to be more difficult if the research is of a type less commonly done in the faculty.

One plausible solution to this challenge is to acquire methodological supervision externally to one's faculty. To facilitate this “matchmaking” process, the assembling of a pool of methodological experts representing the different research profiles and different methods could be of use. This kind of list of names is likely to be created rather easily as a side product of the discussions described in previous suggestions. The list of names would be available to the first supervisors, who are typically experts in the subject of the dissertations, in order for them to recommend further methodological advice for the doctoral students if needed. A specific list would also be useful in cases where new experts and supervisors are just entering the community and have not yet established an extensive network of personal contacts among the other potential supervisors.

5. **Start a national discussion about the philosophy of engineering science and the development of doctoral education**

Systematic training and discussions within faculties and universities of technology provide a good base for discussion at a national level. The association of Academic Engineers and Architects in Finland (TEK) has successfully promoted a discussion about the future of Finnish engineering education during the last decade (see e.g. Korhonen-Yrjänheikki 2011). This discussion has helped to advance cooperation between the stakeholders and the development of the engineering education in Finland, especially at the undergraduate level.

A similar discussion and level of cooperation is also thought to be beneficial with respect to engineering science research and doctoral education. Although there already is a fair amount of discussion and cooperation taking place between the faculties and universities of technology in Finland, taking the discussion to a national level would help in getting other stakeholders (such as companies and research institutes) involved in the conversation, too. In a country the size of Finland, the discussion may well reveal opportunities for practical cooperation, too, such as seminars or material production.

10.3. Evaluation of the process and product

In interpretive research, the quality measures differ from those used in positivistic research, and concepts like validity and reliability are not applicable, at least not in the way that they are in most quantitative studies. The differences between the quality approaches in interpretive and positivistic research were discussed in more detail in section 2.5.1, and the approach towards evaluating the quality of research in this study was more thoroughly discussed in section 5.3.

The concept of generalisability, commonly used as a measure of applicability in positivistic research, is used here as well, as the different conceptualisations of it are considered as being tools applicable to this type of research. However, here, the different types of generalisability are not all viewed as measures of applicability as such, but rather some are perceived as measures for truth-value or consistency. Referring to generalisability is also thought to help readers who are more familiar with positivistic than with naturalistic research to form their own opinion of the scientific quality of the piece of research at hand. Some of the discussion around the conceptualisation of generalisability focuses on the topic of statistical sample-based generalisability and its use in research. This is not of interest from the viewpoint of this study, as the sampling and the methods have not been statistical in nature.

10.3.1. Credibility of the interpretations

In interpretive or naturalistic research, the question of truth-value of the findings comes down to the credibility of the researcher's interpretations (Lincoln & Guba 1984). To enhance study credibility, a reader must be convinced that the interpretations made in the study are also credible to the respondents; not only to the researcher. In this study, credibility has been fostered by the clearly structured, thorough reporting of the process; logical argumentation; theory-guided coding; researcher's and supervisors' familiarity with the studied discipline; and reflection upon the results in view of the earlier research findings and theories.

The data was collected at one university but interpreted in the context of Finnish engineering science. As a critical and paradigmatic case study, this dissertation was presumed to allow for the kind of generalisability in which the researcher generalises from empirical to theoretical statements. Lee and Baskerville (2003) call this "Type ET generalisability." This must be distinguished from what they call "Type EE generalisability", where the researcher generalises from empirical descriptions in one case to the empirical features in another case. This implies that in this study, the empirical findings concerning TUT can be used to help to understand the theoretical phenomenon of the philosophy of engineering sciences in Finland, but it does not allow us to make specific descriptive statements about dissertation research at some other Finnish university or faculty of technology, for instance. This aspect of transferability of the results to other institutions is discussed in the section 10.3.2.

Due to historic reasons and to the smallness of the country, there is a considerable amount of transfer and cooperation between the Finnish universities and faculties of engineering. More than one-third of the pre-examiners and opponents of the studied dissertations came from other Finnish universities, most of which being technical universities or faculties of engineering (see Figure 13). As the statements corroborated rather than contradicted the interpretation made of the dissertations, it is argued here that there appears to be a shared understanding of the qualities of engineering science research across the nation. Thus, it is also argued that the data from TUT can be meaningfully interpreted in a national engineering science context.

The structure of reporting follows the logic of the argument, and has been presented in Figure 1 on page 8. The structure of the diagram identifies the interests of the researcher through specific questions, which are then answered in the respective chapters. The diagram has acted as a "blueprint" for the report, keeping the logic of the argumentation explicit to the researcher as well throughout the inquiry. The process of the empirical inquiry has been described in Chapter Six. The data collection and analysis phases have been explained separately, with the unexpected events also reported (such as one dissertation changing faculty in the middle of the study). This allows the reader to follow in detail what the researcher has actually done during the course of inquiry. Particularly in the Discussions chapter, the interpretations were complemented by direct quotations from the data to allow the reader to judge the credibility of the interpretations.

The analysis was based on theory-guided coding, which uses previously known concepts, but also allows for the emerging of the new ones. The codes and concepts arising from the data were named using the terminology used in the dissertations in order to keep the vocabulary familiar with the target group; i.e., the doctoral candidates in engineering sciences. The preliminary concepts that did not seem to find counterparts in the data were omitted. The evolution of the coding scheme for dissertations from the tentative to the final version is illustrated in Figures 14 and 15 in section 6.2.2. All of this was done in the hopes of ensuring that the interpretation would include what was genuinely present in the data. It was also hoped that terminology had been used that would be understandable to the respondents.

The background and prior experiences of the researcher always have an effect on the interpretations made in a hermeneutic inquiry. In this case, the researcher comes from the same discipline, which was studied, namely engineering. This can be regarded as both an advantage and disadvantage in relation to the credibility of the study. On the one hand, it could be suspected that since the researcher already has experiences and opinions about engineering science, these would influence the interpretation. On the other hand, one could say that since the researcher's background knowledge on the discipline is rather similar to that of respondents, it is more likely that the interpretations credible to the researcher are also credible to the respondents: like minds think alike. In this study, the research familiarity with the disciplinary context is argued to have more pros than cons. It is also likely that also people of other disciplines have some previous knowledge about and attitudes towards engineering. Thus, a different background does not necessarily guarantee an objective view. As the researcher's background was in chemical engineering and the supervisors came from industrial management and information systems, it could be argued that all of them had an appropriate prior understanding of the discipline and its language so as to avoid huge misconceptions, but they also had different enough perspectives within engineering science to avoid bias towards any particular subdiscipline.

Finally, the interpretations were reflected upon in view of the earlier findings and theories in literature. This demonstrated that the interpretations were mostly in line with earlier research and philosophical discussion, and usually provided a deeper rather than contradictory understanding of the subjects discussed. This is argued to have enhanced the general credibility of the findings.

10.3.2. Transferability of the results

In interpretive research such as this, the question of applicability is often answered by the concept of transferability. Transferability is considered to be an empirical matter that depends on the knowing of both the sending context (the context in which the interpretations were made) and the receiving context (the context in which the results are intended to be used). Thus, the transferability inferences cannot be made by the investigator, who only knows the sending context. (Lincoln & Guba 1984) Now the question of applicability of the results becomes largely a question of how the sending context is described to the readers in order for them to make valid judgements about the transferability. Nevertheless, through knowledge of certain contexts, the investigator can give some suggestions about the applicability of the results in them.

The sending context has been described in the sections concerning the case selection strategy (p. 84) and collecting of the data (p. 89). The description of the data collecting principles and process has been written about in such detail that a reader gains understanding about the selection of dissertations as a subgroup of TUT dissertations. The description of the case-selection strategy presents TUT as a part of a national context of engineering education. The data collecting process experienced one unexpected alteration to original plans, as one error in the DPub database was discovered. This event has been explained to the reader, as the aim has been to provide a realistic picture of the process and context instead of a retrospective representation of an ideal process. This too was done in order to enhance the understanding of the genuine sending context.

Tsang and Williams (2012) distinguish between theoretical generalisation, within-population generalisation, cross-population generalisation, contextual generalisation and temporal generalisation. In the framework of hermeneutic or interpretive inquiry, the term *transferability* is grounded in the applicability of interpretation in an empirical context. Thus, what Lee & Baskerville and Tsang & Williams refer to as ET type generalisation is not so much a matter of applicability as a matter of credibility of interpretation, which has already been discussed above. Although the Tsang and Williams classification of the types of empirical generalisation clearly has been developed in a positivistic framework, it is used here as an analogy to discuss the investigator's view of the transferability of the research results across different frameworks.

Within-population generalisation refers to an instance where characteristics of a sample are generalised to those of the corresponding population. Cross-population generalisation means that the generalising is extended from a sample in one population to the members of another population existing in a similar context and period of time. Contextual generalisation means generalising from a sample in one population to members of another population existing in a different context but similar period of time. Temporal generalisation then applies to the case where generalising occurs from a sample in one population at one point in time to the members of the same or different population at another point in time, but in a context presumed to be similar. (Ibid, 13.)

Issues related to temporal generalisation are in this study regarded more as questions of consistency than as questions of applicability. Therefore, they are discussed in section 10.3.3.

Empirical transferability in a national context

Along the lines of within-population generalisation, the researcher believes that the results are largely applicable to all TUT dissertations. Although the sampling was not statistic but selective, it is argued that the profile of the sample in terms of monographs vs. compilations, men vs. women, and different faculties is so similar to the profile of all TUT dissertations from the same time period that it can be considered representative. This does not mean that any single TUT dissertation would include all the common features identified in this study or would exclusively fall into any of the five profiles, as also some of the studied dissertations were simultaneously assigned to two profiles. Instead, it is argued that if all the TUT dissertations from the same time period were to be analysed, one would discover a similar pattern of common features and research profiles as in this study.

The question of transferability of the results to all Finnish engineering science dissertations is considered here analogous to cross-population generalisation. The profiles of the technical universities and faculties are not similar. Not only are the different subdisciplines of engineering science represented differently in different institutions, their relative share of education also varies. Some fields of study, such as biotechnology or civil engineering, are only taught at one or two institutions, whereas a field such as electrical engineering is taught at almost all universities offering engineering education. The Universities of Turku and Vaasa only offer engineering degrees in two fields, whereas Aalto University and the Tampere University of Technology offer degree studies in more than eleven subject areas. At Aalto University, the intake of undergraduate students for computer science is more than double the intake of industrial management students, whereas at Lappeenranta University of Technology, the situation is exactly the opposite. (DIA 2013a&b.) Thus, it is suggested that some transfer of the results can be done across the national context, but it must be done with care. The researcher would expect to also see similar general features in the engineering science dissertations from other Finnish universities, but with different emphases. Also, the occurrence of similar profiles is expected, but not necessarily exclusively (new kinds of profiles may also emerge in some institutions) or exhaustively (some institutions may not have dissertations representing all five profiles). Moreover, the relative share of dissertations falling into different research profiles is likely to be different in different institutions, as there are visible links between certain fields of engineering and certain research profiles.

Empirical transferability in an international context

The transferability of results in an international context is discussed here as an issue of contextual generalisation. Crossing national borders means entering a different world of engineering science dissertations regarding both the context of engineering science and the nature of a dissertation. Finnish doctoral education has been discussed in more detail in Chapter Four, and the nature of Finnish dissertations has been elaborated upon in section 5.2.3. If conducted in its ideal form, the doctoral review and defence process is at least as, if not more, rigorous than the quality assurance process in other countries (Dill et al. 2006, 56). In addition to this, in Europe, the Bologna process has in the past fifteen years systematically steered the structures of higher education towards a similar direction, which has most likely also reduced differences among doctoral education and, in turn dissertations.

What is considered to be engineering science and what engineering science is considered to be like probably has more variation across national cultures than does the role of a dissertation as a demonstration of scientific thinking. The historical development of engineering science as well as engineering education has taken different routes in different parts of the world (see e.g. Channell 2009 for the historical analysis of the emergence of engineering science and Jørgensen 2007 for the historical account of engineering education).

Over the past two centuries, the history of engineering science and history of engineering education have been more or less intertwined, and at least four distinct paths of development can be detected within the western civilisation: the German, the French, the English and the American (U.S.) ones. (Channell 2009, Jørgensen 2007). Crudely simplified, one could suggest that the German path has a two-tier system, in which one tier concentrates on the practical skills and industrial needs and the other on more theoretical and university-like concerns, but with industrial connections. The French path emphasises the theoretical base and natural science in engineering science. The English path weights practical skills and experience heavily. The American path is rooted strongly in an industrial orientation. Although the increasing globalisation of research and education and the blurring of the borders between science and technology have unified engineering science cultures to some extent, the different perceptions of the role and interplay between theory and practice are still reflected in the national educational cultures and practices in engineering science (Jørgensen 2007, 236-237).

Of the four paths mentioned above, the Finnish system has mostly followed the German one. This also applies to the other Nordic countries (Jørgensen 2007, Michelsen 2000). The two-tier system still present in Finland makes the university education in engineering more theoretically oriented, whereas the basis for education at the polytechnics lies in the practice. Similar to the case of Germany, both educational sectors in engineering have strong industrial links. In the early half of the 20th century, the connections between Finnish engineering science research and the research in Sweden and Germany were tight in practice, too, as most of the Finnish engineering science dissertations were completed at Swedish and German technical universities. This was due to the poor condition of the research laboratories at Helsinki University of Technology, which at the time was the only technical university in Finland (Michelsen 2000, 645).

The similar cultural background and the tight connections between Nordic and German engineering research and education suggest that the results of this study are probably most transferable into those national cultures. Naturally, one should keep in mind the same issues governing transferability within the national culture, namely the different profiles and institutional organisation of individual universities. As many of the findings of this study deal with the connection between theory and practice, the direct application of the gained knowledge may not be advisable in educational cultures following divergent paths (e.g. English or French). It can, nevertheless, be used as a starting point for discussion around the issue of the philosophy of engineering science in that particular culture.

10.3.3. Consistency through dependability

The somewhat straightforward question of consistency in positivistic research, typically addressed through reliability, is a trickier business in interpretive research. Lincoln and Guba (1984) answer this question by using a measure of dependability, which means taking into account the changes occurring in a research setting. The practical question to be answered is "How are the factors of possible instability of the phenomenon and the factors of phenomenal or design-induced change taken into account?".

In this study, one possible source of phenomenon instability is the ongoing educational change, which in Europe in largely engendered by the Bologna process. One has to ponder whether the changes in doctoral education have somehow also changed the dissertations during the course of this study. In an analysis of the historical development of engineering education, Jørgensen (2007, 216) states that "since the late 1960s, engineering schools have been surprisingly stable in their basic philosophy regarding the structure and core content of the engineering curriculum." Although the statement likely refers to the bachelor and master levels of education, it seems likely that the same also applies to doctoral education. Since the dissertation-writing process typically takes at least four years to complete in Finland and since the time frame of this study being similar, the phenomenon studied is in itself seemingly rather stable over time. Along the same lines, it is suggested that a temporal generalisation of the results is possible at least for some time into the future. Although education surely changes over time, major changes are likely to take place over decades rather than years.

Another question related to dependability is the possible research-induced change in the phenomenon studied. This is a very pertinent question, especially in those kinds of interpretive studies where data is collected over time through observation or interview techniques. Here, the intervention from the researcher can yield remarkable changes in the situation. In this study, the data was collected retrospectively in the form of written materials. Therefore, the original data could not be affected by the fact that it would be used at a later time for the purposes of this study.

10.3.4. Neutrality of research and interpretations

In interpretive research, the answer to the demand of neutrality in research is sufficient confirmability to make sure that the results can be corroborated by others. In order to ensure this, the process needs to be described in such a way that it is easy for others to follow what has been done and to arrive at the same conclusions. In practice, the confirmability is enhanced through many of the same aspects that improve the credibility of the research.

The most important way to ensure that the reader can follow what has been done is to provide an open and explicit description of the whole research process. This is hoped to have been achieved by 1) keeping the descriptions of different phases of research detailed enough, 2) describing things as they occurred (i.e., also including the unexpected events in the descriptions) and 3) by clearly separating out the different research phases. The first point is perhaps best illustrated in section 6.2.2, which describes the process of theory-directed coding as applied in this study. The third point is very visible within the structure of the research report in three instances: 1) where the description of research philosophy and methodology (Chapter Five) is separate from the description of the research process (Chapter Six); 2) where the description of the reduced data (Chapter Seven) is separate from the description of the findings (Chapter Eight); and 3) where the discussion of the results (Chapter Nine) is separate from the final conclusions, implications and evaluation of the research (Chapter Ten). Keeping the intentions separate from the actual happenings, and the more factual findings separate from the interpretations enables the reader to judge the decisions made by the researcher and to agree or disagree with them. Even if the reader disagrees with some of the interpretations made in the study, s/he can still follow the researcher’s choices and understand them from the researcher’s point of view, if the background assumptions and the standpoint of the researcher have been explained well enough.

The openness of the description also extends to the data used. The list of studied dissertations can be found in Appendix 1, and all of them are available for anyone to access from the TUTPub database. Also, the statements concerning the dissertations are public, albeit not published. This brings certain ethical issues into question, as the authors’ of the dissertations were not asked for permission to use the dissertation as data for this study. However, permission was not considered to be necessary since the dissertations and statements are public by nature and are used here for their primary purpose; that is, the dissertations as demonstrations of one’s ability to think scientifically and the statements as evaluations of this ability. Alongside the decision made to include the list of dissertations in the report came another decision to maintain the quotations from the dissertations in their original format. As safeguarding the origins of the quotations was unneeded, keeping the quotations untouched presents them in the same way to the readers as to the researcher.

10.3.5. Publicity of research

The guarantee of the publicity of the findings of the inquiry stems from the Finnish system of evaluation of a dissertation. The study will be publicly defended, and it also has to be publicly displayed at the faculty at least ten days before the public defence (TUT Degree Regulations 2013, 31 §). All data used in the study are also made public, as explained in the previous section.

Regarding the publicity of the research process, associated questions come down to the same elements found in questions of credibility and neutrality. Once again, the answer is an open and explicit description of the whole process, with a more naturalistic than idealistic approach to the presentation.

10.3.6. Novelty of results

As discussed earlier in section 3.1.2, the philosophical discussion around engineering science is scarce, and empirical studies on the topic even rarer. The objective of this study has been to gain a better understanding about the nature of engineering science as a scientific discipline. To the extent that this has been successful, the knowledge produced is new not only to the researcher but also to society at large.

Through answering the research questions, the study yielded new knowledge about the convergence and divergence of engineering science, the philosophy and technical matrix of engineering science and the challenges of engineering science research. In Gregor's (2006) words, this would be classified as “Theory for Explaining.” Some of the knowledge was not necessarily new in the sense of being surprising or unexpected, as it has already been proposed in theoretical or philosophical analysis. However, this knowledge may also be argued to have novelty value, as the empirical evidence for the theoretical suggestions is new. Some of the findings, such as discovery of different research profiles in engineering science had not been proposed earlier at all, and some of the findings contradict earlier propositions from the literature, such as Eekel’s (2000) proposal for the definition of engineering design science.

In addition to the original objective, the results also have novelty value from another perspective. Although the starting point was not to understand the engineering sciences as being representative of design science, the study confirmed the strong design science character of engineering science, which had already been anticipated by many earlier. Despite this anticipation, design science approaches and methodologies have not been systematically developed within the engineering sciences, but the most influential openings have come from other disciplines such as information science (see Hevner et al. 2004) and management science (see van Aken 2004). Already being a diverse discipline, engineering science also demonstrates diversity when it comes to design science. The research profiles discovered concerning experimental design science, mathematical design science and naturalistic design science reflect novel philosophical and methodological features, also with respect to the concept of design science.

10.4. Suggestions for further research

To continue the trajectory of discussion and development, the research topics included in this dissertation need to be further investigated. There are several different directions towards which new studies could aim.

An obvious continuation from a single case study would be to study the phenomena in other settings of the same phenomena; i.e., in other Finnish technical universities and faculties. This could deepen the understanding of the actual convergence and divergence in engineering science and possibly reveal new research profiles in addition to the five already discovered. One interesting option would be to choose one subdiscipline and look at it through the lens of all the Finnish universities at which it is taught. This would give insight as to how much organisational variation the research contains.

Dissertations and statements were chosen as data with the hope of understanding the actual theory-in-use rather than the espoused theories of engineering science. Documents were utilised instead of interviews because it was suspected that it might be difficult for the doctoral candidates to express their philosophical views. However, discovery of people's personal conceptions of these matters is another important side to the narrative which should be investigated.

The research profiles discovered contained three different approaches to design science. Although engineering science has often been nominated as a typical design science, there is little analysis of the kind of design science research which engineering science represents. This kind of study would again deepen our understanding of engineering science, but it could also expand our thinking of design science philosophies and practices.

In this study, it was noticed that the researchers perceive the contributions of their research very differently from each other, and quite a few of them do not even explicate the contributions. Also, the new knowledge created in dissertations was described and conceptualised in a rather versatile manner. With engineering knowledge having already received a good deal of attention, a better analysis or classification of engineering science knowledge created through engineering science research would be interesting and useful to obtain. Like the more general concept of engineering science, the question concerning the nature of engineering science knowledge could be approached via documents, but also through interviews.

As much of the knowledge related to the ways of doing research is implicitly transferred through social practices, a more sociological study of the academic tribe of engineering science would probably complement well the philosophical nature of this study. This kind of study could be especially useful in trying to understand the contradictions indicated in this research between espoused theories and theories-in-use.

Finally, studying everything suggested above in another cultural setting, or even at an international level, would be highly challenging and interesting. This kind of global view of engineering science may not even be possible, but understanding just fragments of it could assist international communities comprised of representatives of both engineering and engineering science with internal cooperation and could promote interaction with society at large.

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Appendix 1. Dissertations included in the data

Aho, Johanna: Rheological Characterization of Polymer Melts in Shear and Extension: Measurement Reliability and Data for Practical Processing

Aittala, Pekka: Computational Study of Charge Transfer in a Porphine-Quinone Complex and Novel Alkoxypyridylindolizine Derivatives

Antikainen, Maria: Facilitating Customer Involvement in Collaborative Online Innovation Communities

Bhuiyan, Mohammad Zahidul Hasan: Analysis of Multipath Mitigation Techniques for Satellite-based Positioning Applications

Eteläaho, Pirkko: Melt-Compounded Thermoplastic Nanocomposites: Processing, Structure and Properties

Hakulinen, Tommi: Towards Stabilized, Short Pulse Q-switched Fiber Lasers

Hämäläinen, Päivi: Global Estimates of Occupational Accidents and Fatal Work-Related Diseases

Hidalgo Stitz, Tobias: Filter Bank Techniques for the Physical Layer in Wireless Communications

Hiltunen, Iiro Tapio: Tools for Cryogenic Design of Superconducting Induction Heater

Hytti, Heli: Energy Efficient Measurement and Signal Processing for Self-powered, Lamb-wave-based Structural Health Monitoring System

Jääskeläinen, Aki: Productivity Measurement and Management in Large Public Service Organizations

Jokinen, Kai: Inverse Methods for Continuous Balancing of Flexible Rolls

Kaunonen, Anna: The Development of Industrial Buyer-Seller Relationships in a Chinese Context

Keränen, Janne: Towards Computational Electromagnetics in Spacetime

Kivikko, Kimmo: Assessment of Electricity Distribution Reliability - Interruption Statistics, Reliability Worth, and Applications in Network Planning and Distribution Business Regulation

Kokko, Kati: Reliability of ACA Joints with Conformal Coatings in Harsh Environments

Krogerus, Tomi: Feature Extraction and Self-Organizing Maps in Condition Monitoring of Hydraulic Systems

Laakso, Kimmo: Matkaviestinnän sääntely ja sen vaikutukset Suomessa 1985-2015

Laaksonen, Anssi: Structural Behaviour of Long Concrete Integral Bridges

Laine, Kari: Fostering Innovation in Collaboration between Higher Education and Industry. A Systemic Model Based on Case Study

Lanz, Minna: Logical and Semantic Foundations of Knowledge Representation for Assembly and Manufacturing Processes

Lintinen, Kalle: Photopolymerizable Liquid Fullerene, Phthalocyanine and Porphyrin Derivatives -Synthesis, Analysis and Photocurrent Generation

Lundan, Miikka: Packet-Switched Streaming Service in Non-Bitrate-Guaranteed Mobile Networks

Määttä, Sanna: Modelling Embedded Applications for On-Chip Multiprocessing Platforms

Magnusson, Camilla: Text Visualization for Competitive Intelligence

Mahlamäki, Tommi: The Influence of Personality on the Job Performance of Key Account Managers

Merilampi, Sari: The Exploitation of Polymer Thick Films in Printing Passive UHF RFID Dipole Tag Antennas on Challenging Substrates

Mettänen, Marja: Measurement of Print Quality: Joint Statistical Analysis of Paper Topography and Print Defects

Nevatalo, Laura: Bioreactor Applications Utilizing Mesophilic Sulfate-Reducing Bacteria for Treatment of Mine Wastewaters at 9-35°C

Niemelä, Tiiu: Self-Reinforced Bioceramic and Polylactide Based Composites

Ollila, Samuli: Lateral Pressure in Lipid Membranes and Its Role in Function of Membrane Proteins

Orsila, Heikki: Optimizing Algorithms for Task Graph Mapping on Multiprocessor System on Chip

Palmroth, Lauri: Performance Monitoring and Operator Assistance Systems in Mobile Machines

Peltotalo, Jani: Solutions for Large-Scale Content Delivery over the Internet Protocol

Penttinen, Ilpo: Adoption of Eco-Efficiency in Strategic and Operational Management of Industrial Small and Medium Size Enterprises

Pölönen, Harri: Quantification of Biomedical Data with Stochastic Parametric Models and Numerical Optimization

Pulkkinen, Pietari: Multiobjective Genetic Fuzzy Systems in Data Classification and Regression

Rasila, Heidi: Customer Experience in a Landlord-Tenant Relationship

Rudzki, Jakub: Software Quality Concerns in a Commercial Setting

Siikarla, Mika: A Light-weight Approach to Developing Interactive Model Transformations

Takala, Markus: Electrical Insulation Materials towards Nanodielectrics

Turunen, Seppo: Weak Signal Acquisition in Satellite Positioning

Tyvimaa, Tanja: Developing and Investing in Senior Houses in Finland

Uusitalo, Jukka-Pekka: A Novel Digital Hydraulic Valve Package: A Fast and Small Multiphysics Design

Välimäki, Antti: Pattern Language for Project Management in Global Software Development

Väre, Jani: Techniques for Signaling and Service Discovery in DVB-H Networks

Vivo, Paola: Multilayered Thin Films for Organic Photovoltaics

Wendel, Katrina Elizabeth: The Influence of Tissue Conductivity and Head Geometry on EEG Measurement Sensitivity Distributions

Ylä-Anttila, Kimmo: Verkosto kaupunkirakenteen analyysin ja suunnittelun välineenä

Zhao, Lu: Adaptive Disconnection Based Brain Hemisphere Segmentation in MRI: Applications to Brain Asymmetry Studies

Appendix 2. Illustration of the coding process in practice

This appendix illustrates how the theory-guided coding applied in this study proceeded in practice. The following example shows how the concept of “inquiry process” included in the tentative coding scheme turned into the concept of “empirical work” in the final coding scheme. In the course of coding the concept of “methodology,” which in the tentative coding scheme was presented as a sub-category for the inquiry process but evolved into the sixth main category in the final scheme. Therefore, the “inquiry process” of the tentative scheme was in a way replaced by two categories: empirical work and methodology. The emergence and development of the concept of “methodology” and its subcategories is not included in this example.

The illustration is retrospective and may not include all the side paths of the actual coding process. Nevertheless, it hopefully gives an idea of the actual thinking process of the researcher while coding the data. The original coding log was written in Finnish, but the excerpts appropriate to this example are presented as translations. The original print out of all the LoI quotations included 50 lengthy quotations (one from each studied dissertation), out of which four have been chosen here to demonstrate the use of codes.

Translated excerpts from the coding log:

12.09.2011 Creating the tentative coding scheme in Atlas.ti

14.09.2011 Coding the first documents: picking up quotations for the primary categories [philosophical commitments, inquiry process, evaluation, end product, purpose] and pointing out obvious sub-categories, marking the missing things with open coding

20.09.2011 Continuing the first round of coding .. Aim of the next round to come up with [first level of] subcategories that fit the data better...

14.10.2011 Moving to the methodology-family [i.e. inquiry process] Won't work like with philosophy or purpose/objectives, as the codes and quotations are already so many --> looking at the details hides the big picture. ... Next trial: look for the "beef" i.e. mark with a new code "Logic of Inquiry" all the quotations telling what will be or is done in course of work (cannot necessarily be found in all the dissertations)

20.10.2011 Hunting for the Logic of inquiry continues. Some kind of methodological leading thought (?) excerpted from every dissertation. Could be looking more closely for:
- Is it a series of separate endeavours, entity with certain phases, one big thing or something else
- What kind of elements of work does the research contain: laboratory work, field work, simulation, building a physical model...
- What is the logic behind the inquiry: hypothetico-deductive, hermeneutic, design, combination of the mentioned above, something else
- Are there any named methods, methodologies or approaches

20.10.2011 Printing out all of the LoI-quotations for "manual coding"

21.10.2011 There seem to be four different "forms of empirical work" arising from the data: laboratory work (L), field work (K), simulation (S) and prototyping (P). Marked accordingly to the printout with one or several appropriate coded. It also seems that the empirical data has (at least) three different functions: collecting information from the target (I), testing a designed or proposed construction (T) and designing a construction (D). These too marked on the printout (one or several per dissertation).

27.10.2011 Replace the "logic of the inquiry" coding with the codes denoting the type and function of empirical work

Examples of quotes from "LoI" print out and their coding:

"In-house-made masterbatches were compared with their commercial counterparts in order to verify the current quality level on nanocomposite production in our laboratory."
→ laboratory work (L) for gathering information (I)

"In this study typical fault situations in the hydraulic cylinder and valve, and the performance of data analysis methods are tested: first with three test systems in the laboratory, and finally with a work machine, which is a forklift in this study."
→ laboratory work (L) and Field work (K) for testing a method (T)

"The performance of the proposed as well as the state-of-the-art techniques has been tested and evaluated through extensive simulations in terms of different performance criteria."
→ simulation (S) for testing a technique (T)

"While designing superconducting systems, cryogenics and coil design require many parameters and data which is often unavailable. Measurements and simulations for these parameters are needed to backup the design."
→ simulation (S) and laboratory measurements (L) for designing a construction (D)

Resulting changes in the coding scheme:

Tentative coding scheme

Inquiry process

- Method
    - Hypothetic-deductive
    - Hermeneutical
    - Design
- Methodology
    - Certain / named
    - Not mentioned
    - Described
- Logic
    - Inductive
    - Abductive
    - Deductive
- Approach
    - Quantitative
    - Qualitative
    - Mixed
- Source of knowledge
    - Transfer from science
    - Direct trial
    - Production
    - Design practice
    - Mathematical engineering research
    - Invention

Final coding scheme

Empirical work

- Type
    - Field research
    - Laboratory work
    - Simulation
    - Prototyping
- Function
    - Gather information
    - Test a method / construction
    - Advance a design

Methodology

- Object of methodology
    - Data acquisition
    - Data analysis
    - Modelling/design
    - Preparation
- Other methodological aspects
    - Use of case method
    - Identified research approach

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ISBN 978-952-15-3619-9
ISSN 1459-2045