THESIS FOR THE DEGREE OF LICENTIATE OF
ENGINEERING EDUCATION

Engineering Students' Ways of Relating to Wicked Sustainability Problems

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Cover:
Illustration of an understanding of a wicked sustainability problem as an integrated whole that is composed of parts of the problem (red) and parts of the solution (green), which are related to each other in complex ways. For a detailed description, see paper II.

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Abstract

This licentiate thesis constitutes a part of a larger research effort that aims to provide a theoretical framework for understanding and working with engineering students' ways of relating to wicked sustainability problems (WSPs) on the basis of conceptual, empirical, and practical considerations. Thus, the project aims to contribute to an understanding of how engineering education can support students in developing the capabilities that they need to actively participate in discussions about sustainable development and to constructively deal with WSPs.

The concept of perspectives provides a point of departure for the research. Paper I introduces a conceptual framework for conceiving of and communicating about perspectives and perspective processes in the context of engineering education for sustainable development. In Paper II, four qualitatively different ways in which engineering students understand and approach a specific WSP are described based on an empirical study. The results from the study suggest that a partial experience of the complexity of WSPs may lower rather than increase students' abilities to deal with WSPs, and that educators therefore should pay attention to support the students in progressing beyond this level. A combination of the results from the two papers provides input for discussions about what it may mean to fully appreciate the complexity of WSPs, and a basis for more practice-oriented research in line with the aim of this research.

Keywords: Engineering education; Engineering students; Wicked sustainability problems; Sustainable development; Perspective; Phenomenography; Complexity.

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Preface and Acknowledgments

Pursuing a PhD program has much in common with a mental and intellectual journey. Just as any physical journey to unknown countries and cultures, it includes both intense challenges and fulfillment. It provides experiences of exhilaration and joy in parallel with feelings of doubt, desperation, and a most profound confusion.

When I started my PhD studies, I had a strong feeling of purpose: "EESD [engineering education for sustainable development] is about saving the world by teaching students of engineering how to think. I mean not only think, but really 'Think'. That's what I wanna do, that's my life's calling, a PhD in EESD to save the world" (research diary, 2011-09-12, English in original). This purpose was linked to the experiences from engineering education [EngE] that I had gained both as a student and as an educator in EESD.

Eventually, the security of this clear purpose eroded away as I started to wonder what I was actually doing all day and what it was good for. As a PhD student in an emerging research field, a newly formed and still evolving research group, no ideas of what pursuing a PhD actually meant, and no PhD peers in our group, I had troubles finding a foothold and a context to ground my research in. I kept wondering where in the huge maze of research fields I belonged and which groups I should try to associate with to get over the loneliness of being a "lost" PhD student. While confusion and insecurity kept me feeling on edge, I also realized that I did not actually need or want to simply belong to a fixed discipline with ready-made standards, procedures, and assumptions. I realized that it is "the uncertainty and freedom themselves, which make room for creativity and new ideas" and that "this actually [was] what I wanted to have for my studies – I would only have felt trapped if I had been given clear guidelines… but even though I [was] aware of all of this, I [could] still feel overwhelmed by the situation" (research diary 2011-09-29, translation from Swedish).

I frequently experienced frustration about uncertainty, complexity, and about feeling like being in a "limbo" state. During my first term of studies, I enrolled in a course on action research. In my final essay, I reflected on my difficulties with overcoming what I perceived to be my preconditioned engineering way of thinking:

"Throughout this course, I caught myself over and over again in the act of demanding precise definitions of concepts used, asking how they related to each other, and looking for simple cookbook-descriptions of how to do action research. I often felt frustrated by the inherent ambiguity of action research and demanded – in line with a mechanistic view of science – a standardization of action research as a method rather than a methodology" (action research course exam essay, 2011-10-20).

In another reflection about the course (2011-10-31), I started to see connections between my own learning and the learning I wanted to help my students to do:

"Here was I, wanting to challenge engineering students' perspectives and worldviews and was not even ready to challenge my own! I wanted to do AR [action research], but I wanted to do it 'the right way'...".

* * *

Time flies and I have learnt a lot during the two and a half years that I now have been working on my PhD project. I have learnt to live with a little more ambiguity and uncertainty, I have learned more about what it means to do research in EER, and what it means to teach in EESD. I still have a lot to learn and I am looking forward to the remainder of my program. The connection between my research and my teaching has grown stronger over time so that they are now starting to become truly integrated – which in turn increases the feeling of meaning in the work I do. A few months ago, I caught myself "sitting and observing the project presentations and discussions in the ethics course and thinking to myself that I would like to know the final results of my phenomenographic study in order to better know how to behave and what to focus on in these sessions. ☺ What a wonderful feeling that what I do might actually be valuable! Even if the feeling still is veeeery diffuse und I don't quite know HOW it will be valuable. But somehow, the idea of transgressing the 'chaos'-stage seems important and useful. Because in the ethics course, all discussions stop at the stage of stating that 'it depends'!" (research diary 2013-11-04). One of my main ambitions with my PhD project is to be able to actually make a difference. I would like my work to make even just a small impact on EESD teaching and learning.

I would not have made it this far on my journey without the ongoing support of others. First of all, I want to thank Chalmers' board of undergraduate and master's studies for providing the necessary financial support for my research. I am proud to work at a university where educational questions are taken seriously. I am also deeply grateful for the wonderful people in my life who have supported me throughout my journey, and who I know will continue to be there for me even during the second half of my PhD studies. In particular, I want to thank my supervisors Magdalena Svanström, Åke Ingerman, and John Holmberg for their careful guidance and continuous support and encouragement. Special thanks also to Andreas Gunnarsson, Maria Berge and Jens Kabo for carrying me through the most challenging first year of my studies, and Jens also for continued support. I am grateful for my family who provides a realistic perspective on life and lets me know that they love me whether I succeed in my studies or not. I am also grateful towards my CUL PhD student group consisting of Ingela Bursjöö, Helena Sagar, Maria Ferlin, Birgitta Berne, Marlene Sjöberg, Miranda Rocksén, and group leaders Angela Wulff, Frank Bach and Dawn Sanders for sharing the ups and downs of our research studies and for invaluable feedback on my ongoing work. I want to thank my colleagues at the Department of Applied IT for the friendly and supportive atmosphere at our work place. Last but not least, my hang gliding, paragliding, Ultimate Frisbee, high school and college friends: thanks for playing with me and by that keeping me sane even when everything I thought I knew, over and over again, gets thrown upside down.

Gothenburg, January 2014

List of acronyms

EngE	Engineering Education
EER	Engineering Education Research
EESD	Engineering Education for Sustainable Development
EnvE	Environmental Education
EnvER	Environmental Education research
ESD	Education for Sustainable Development
PhD	Doctor of Philosophy
REESD	Research in Engineering Education for Sustainable Development
RESD	Research in Education for Sustainable Development
SD	Sustainable Development
WSP	Wicked Sustainability Problem

Engineering Students' Ways of Relating to Wicked Sustainability Problems

1 Introduction

This licentiate thesis presents research on engineering students' ways of relating to wicked sustainability problems (WSPs). It constitutes the first half of a PhD project that aims to provide a theoretical framework for understanding and working with engineering students' understandings of and approaches to WSPs on the basis of conceptual, empirical, and practical considerations.

The research has a transboundary character in many ways as it originates from *practical* difficulties in *engineering education for sustainable developments (EESD)* that are addressed *theoretically* in the tradition of *engineering education research (EER)* while also drawing heavily on *research in education for sustainable development (RESD)*. An explicit goal of the research is to serve as a platform for researchers and practitioners from the fields of EER, RESD, and EESD to communicate and collaborate more effectively around issues of learning related to WSPs.

1.1 Motivation for research focus

The motivation behind this research is found on different levels of engagement. Fundamentally, the research is driven by a desire to enable students of engineering to actively participate in debates about Sustainable development (SD), and to deal with complex sustainability problems in productive ways. More specifically, it originates from the author's personal experiences of a lack of critical discussions and considerations of contexts and values in her undergraduate studies in engineering nanotechnology, as well as a lack of practical and theoretical guidance as a novice teacher in EESD. In particular, students' experiences of frustration about the complexity and uncertainty that are inherent in WSPs (see section 2.2), and educators' experiences of difficulties in providing fruitful learning experiences related to these problems triggered an interest in students' ways of relating to WSPs in the context of engineering education (EngE).

An important question in this context is what it is that is needed for students to develop capabilities to effectively deal with WSPs. The research in engineering education for sustainable development (REESD) literature provides some conceptual compilations of what could be important competencies in the context of EESD, such as systems thinking competence; anticipatory competence; normative competence; strategic competence; interpersonal competence; critical, creative, and reflexive thinking; perspective shift and perspective integration competence; research and learning skills; and problem solving skills (e.g. Wiek, Withycombe & Redman, 2011; Svanström, Lozano-Garzía & Rowe, 2008; and Wals & Blaze Corcoran, 2006). Based on the characteristics of WSPs, as described in section 2.2, it seems that all of the above competencies would be required for being able to deal with such problems. Since concrete descriptions of these competencies are lacking in the literature, and since they are often interrelated in complicated ways (Wiek, Withycombe & Redman,

2011), the educators' task to design appropriate and effective educational activities is challenging. The lack of concretion related to these competencies also hampers theoretical and empirical work related to WSPs, which otherwise could provide a better understanding of what is needed to be able to effectively deal with WSPs.

In the research underlying this thesis, the concept of *perspectives*, which is related to for example perspective shifting and perspective integration competencies, has been chosen as a point of departure for starting to create an understanding of students' learning related to WSPs. Other points of departure could have been chosen, but the concept of perspectives was identified as particularly relevant.

In the Education for Sustainable Development (ESD) literature, the term "perspectives" is frequently used to describe the fact that WSPs can be understood in many different contexts and from many different angles (e.g. Wals & Blaze Corcoran, 2006; Svanström, Lozano-Garzía & Rowe 2008; Kates, Parris & Leiserowitz 2005). For example, Wals and Blaze Corcoran (2006, p. 107) focus on transformative learning for SD, which they write, "requires permeability among disciplines, the university and the wider community, and between cultures, along with the competence to integrate, connect, confront, and reconcile multiple ways of looking at the world." They further describe four thematic areas within each of which students should learn to "shift back and forth" between different perspectives. A more sustainable world, Wals and Blaze Corcoran write, requires constant transcultural, transgenerational, transdisciplinary, and transnational perspective shifts. Other scholars have specifically stressed the importance of transboundary approaches, such as inter- and transdisciplinarity (e.g. Hirsch Hadorn, Bradley, Pohl, Rist & Wiesmann 2006; Polk & Knutsson 2008; Max-Neef 2005). As described in Paper I, this previous work has provided interesting starting points for discussions about perspectives in EESD on which to build a better theoretical and practical understanding of engineering students' learning related to WSPs.

1.2 Research aim and questions

As stated above, this PhD project aims to provide a theoretical framework for understanding and working with engineering students' ways of relating to WSPs on the basis of conceptual, empirical, and practical considerations. On a more general level, the research also aims to contribute to the development of theoretical understandings of EESD learning objects, to improve the integration of EESD in EngE and of REESD in EER, to contribute to international discussions in EER and REESD, and to facilitate communication between research and practice in EESD. This licentiate thesis includes two scientific publications that address these aims.

The first publication (Paper I) is currently under consideration for publication in the European Journal of Engineering Education. It serves the purpose of providing a conceptual foundation for further research about learning objects related to complex sustainability problems in EngE by *giving substance to what it can mean to consider a multitude of perspectives in relation to sustainability challenges, particularly in the context of EngE.* In the paper, a conceptual model over perspectives and perspective processes in EESD is presented. On the basis of the

work with this model, the following research question was formulated: *In what qualitatively different ways do students of engineering understand water shortage in Jordan, as an example of a WSP, in a discursive problem-solving context?* This question is answered in Paper II, which will be submitted to a scientific journal in the near future.

1.3 Summary of the included papers

The main focus of Paper I is the concept of *perspectives* in EESD, or more specifically, engineering students' perspectives towards an *object*, in this case water shortage in Jordan, which is framed as a *complex challenge to SD*. The main contribution of the paper is a conceptual framework that suggests a way of conceiving of and communicating about these perspectives and related processes in the context of EESD. In the paper, *coverage*, *depth*, and *complexity* are introduced as three characteristics of perspectives that can be used to describe differences and similarities between individual perspectives. Further, different ways in which students approach the given problem are described as operative processes (*perspective formation*, *perspective shifting*, and *perspective integration*) and reflective processes (*perspective perception*, *perspective reflection*, and *perspective evaluation*). The context of EESD is held central in the descriptions. An explicit ambition is to contribute to the development of educational activities that enable students to develop the capabilities they need to actively participate in discussions about SD, and to deal with complex sustainability problems in their future professional lives.

The concepts that are introduced in the paper provide a set of ideas that the authors, based on their own practical experiences, regarded as helpful in reflecting on the nature and aims of different EESD practices. The approach taken is rather abstract as the intention is not to provide an analytical framework, but a basis of meaning on which discussions about perspectives and the use of multiple perspectives in EESD is made possible.

The main contribution of Paper II is a set of four empirically derived and logically related categories that describe qualitatively different ways in which students of engineering understand and approach water shortage in Jordan as an example of a WSP. Students holding conception A, *simplify and avoid*, express a rather naïve and vague conception of the problem, which does not allow them to actively take responsibility for finding a solution. Conception B, *divide and conquer*, describes an instrumental approach towards the problem that aims to overcome the complexity inherent in the situation. In conception C, *isolate and succumb*, the complexity is acknowledged but becomes overwhelming, leading students to conclude that it is impossible to find a solution to such a messy problem. Finally, students holding conception D, *integrate and balance*, accept the fact that conflicts of interest are present in the problem and cannot be avoided. They give up the notion of unambiguously "solving" the problem and instead attempt to manage the complexity in a way that respects the rights and needs of different stakeholders.

These four categories are organized hierarchically according to an increasing complexity of the described conceptions from A to D. On the basis of this organization, critical differences between the conceptions are identified, which provide insights into what it may take for students to develop and express more complex conceptions. Non-critical differences between

the conceptions, on the other hand, are not focused upon in the article, irrespective of their potential relevance for EESD. It is observed that the level of complexity of the students' understanding may not necessarily be linearly related to students' ability to actively and productively deal with the given problem.

1.4 Structure of the thesis

In this thesis, the research that is presented in the papers is positioned in a wider context of research and practice, and connections between Paper I and II are explored. The aim is to provide an overview of the results, the significance, and the implications of this research, and to create a basis on which future research can build. Figures and detailed descriptions from the papers are not reproduced here; the reader is asked to refer to the papers instead.

In section 2 of this thesis, the concepts of SD and WSPs are introduced, and their meaning in the context of this thesis is explained. The interdisciplinary research context of EER, RESD and REESD, in which the work is based, is explored in section 3. Section 4 deals with methodological considerations related to the research fields and the approaches taken in Paper I and II. That section also includes a comparison between these approaches in order to facilitate the synthesis of the results. The results from the papers are summarized and integrated in section 5, with the aim to provide a more powerful understanding of some key questions related to engineering students' learning about WSPs. Finally, theoretical and practical contributions of the research are discussed and an outlook towards possible future research is provided in section 6.

2 Important concepts

2.1 Sustainable development (SD) as an ambiguous and contested concept

As described in section 1.1, one of the fundamental motivations behind the research presented in this thesis is related to students' abilities to deal with WSPs in constructive ways. This focus on WSPs entails a view of SD as something that is complex and ambiguous, but it also suggests that sustainability problems need to be dealt with, and thus that SD, in general, is something that is desirable. A second motivation for the research is related to engineering students' abilities to participate in debates about SD. Underlying this motivation is a view of SD as a contested and debated concept, and an assumption that it is important to be able to understand different stakeholders' views of how the concept should be interpreted. In this section, a short overview is provided over some of the most widespread conflicts of interpretation related to SD with the aim to clarify what is meant with the classification of SD as an ambiguous and contested concept. SD is here used interchangeably with the term sustainability. The variance of interpretation of each of these two terms (Clark, 2010; Kates, Parris & Leiserowitz, 2005; Connelly, 2007) is here assumed to outweigh the slight semantic differences *between* the terms.

According to Mebratu (1998), all interpratations of the term SD, both historically and since its wide-spread introduction in the famous Brundtland report in 1987, have some important common elements. He claims that all parties agree that "the world is faced with an environmental crisis" and realize that it is necessary to "make a fundamental change to overcome the crisis" (Mebratu, 1998, p. 504). In relation to the concept itself, he concludes that "living in harmony with nature and with one another … is the logical essence of what we, today, call sustainability" (Mebratu, 1998, pp. 517-518). However, these common elements are rather abstract and unspecific, and Mebratu himself called SD, as it is used today, a "catch phrase (…) with very diverse interpretations" (1998, p. 502).

In 1999, the US National Research Council (in Clark 2010, pp. 55-56) identified four questions that are central to most interpretations of the term SD. These questions are: 1. What is to be sustained? 2. What is to be developed? 3. What is the relation between what is to be sustained and what is to be developed? And 4. Over what scales in space and time are those relationships meant to hold? The answers to these questions differ widely among the different interpretations of SD (Kates, Parris & Leiserowitz, 2005).

The answers to the first question, what is to be sustained, cover both anthropocentric views of "nature or environment as a source of services for the utilitarian life support of humankind" and biocentric views in which nature is "valued (…) for its intrinsic value" (Kates, Parris & Leiserowitz, 2005, p. 11). The second question, what is to be developed, poses a further point of disagreement. While some argue that economic development is a necessary condition for being able to sustain anything at all, others advocate a shift of focus from economic to human development with indicators such as "life-expectancy, education, equity, and opportunity". Human well-being becomes a central notion for the proponents of the latter view (Kates, Parris & Leiserowitz, 2005, p. 11). Kates, Parris, and Leiserowitz (2005) suggest that most

interpretations of SD stress the need to link that which is to be sustained with that which is to be developed (question 3). However, since SD in itself can be described as an oxymoron and presents an idealized idea rather than an attainable goal (Stables, 2013), different interpretations naturally ascribe different relative emphasis to the two parts of the term, i.e. some interpretations focus more on preservation (sustainment), while others see development as central. In addition, disagreement reigns over the appropriate time span during which something should be sustained (question 4); interpretations in this regard range from advocating sustainability over the time span of one generation to demanding sustainability "forever" (Kates, Parris & Leiserowitz, 2005, p. 12). This disagreement is closely related to the concept of intergenerational justice, i.e. the relative rights of current versus future generations. Another point of disagreement is found in discussions about intragenerational justice. For example, questions arise whether everybody should be treated equally, or whether the right to equal opportunities should be given predominance. In the first case, some people will be considerably worse off due to unequal starting points, while in the second case, some people will experience that they are treated unfairly since they get a smaller share of the available resources than others who are less well off from the beginning.

Despite, or maybe because of, these different interpretations of the term SD, it has reached wide-spread acceptance in areas such as politics, marketing, education, and media. Stables (2013, p. 183) describes SD as a "political slogan" that is "able to attract sympathy and support from an ideologically diverse range of people", thus masking the inherent contradictions and ambiguities of the term and falsely suggesting that it is possible to achieve both sustainment and development without the need of trade-offs, compromises and sacrifices. Stables sees a great danger in using such a terms, since "what works for politicians is not always what works in other contexts, and the context of impending ecological disaster is not one that is generally held to allow for huge interpretative variation" (Stables, 2013, p. 183). Furthermore, the ambiguity of the term may allow different interest groups to create their own definitions of SD – according to their own needs. Since the concept itself is widely accepted, if one such definition were to gain ground, a single group or institution could potentially strongly influence the way human societies interact both with each other and with the natural environment (Mebratu, 1998, p. 518).

Contrary to these arguments, Kates, Parris and Leiserowitz (2005, p. 20) suggest that it is the very ambiguity of the term that is its real strength, because "the concrete challenges of sustainable development are at least as heterogeneous and complex as the diversity of human societies and natural ecosystems around the world. As a concept [SD], its malleability allows it to remain an open, dynamic, and evolving idea that can be adapted to fit these very different situations and contexts across space and time. Likewise, its openness to interpretation enables participants at multiple levels, from local to global, within and across activity sectors, and in institutions of governance, business, and civil society to redefine and reinterpret its meaning to fit their own situation".

Whatever one's position is on the usefulness or harmfulness of the concept, there is no denying that SD has today become a political reality as it pervades most parts of public life, both locally and globally. It is no longer possible to refuse to be concerned with the concept,

least of all in the context of education. In his critique of sustainability and SD as regulative ideas, Stables (2013, p. 185) strongly critiques the incorporation of ESD into higher education because he sees ESD as furthering an externally defined political agenda (i.e. SD): "In universities and elsewhere, educators are not here primarily to serve the agenda of environmental politics, but to reflect on the human condition in a much fuller and richer sense. Such reflection will inevitably impact on that agenda, but should not be determined by it". Stables argues that education should not adopt the political rhetoric of SD. He envisions a "disillusioning role" of education. Such an education would highlight limits and vulnerabilities and focus on possible conflicts of interest, rather than falsely indicating the possibility of win-win solutions in all situations.

In this thesis, the underlying ambition to prepare students for dealing with the complexity and ambiguity of SD and WSPs entails that ESD is not seen as conflicting with, but contributing to, the goals of education envisioned by Stables. This interpretation of ESD is in line with widely held understandings of ESD learning processes and learning outcomes as described in Tilbury's (2011) review of the ESD literature, which was commissioned by the UNESCO in the context of the United Nations Decade of Education for Sustainable Development 2005-2014. For example, Tilbury identifies learning outcomes such as "learning to ask critical questions", and "learning to clarify one's own values" as important in ESD, both of which have a high potential to provide the critical perspectives that Stables calls for. In terms of learning processes, Tilbury identifies, among others, "processes of collaboration and dialogue (including multi-stakeholder and intercultural dialogue)" and "processes which engage the 'whole system'". Again, such processes support rather than inhibit a profound engagement with what Stables calls the "human condition".

2.2 Wicked Sustainability problems (WSPs)

Seager, Selinger and Wiek (2012) argue that complex sustainability problems are included in a specific class of problems that has previously been identified in the area of social planning. In 1973, Rittel and Weber introduced the concept of *wicked problems* to describe situations in which it is "less apparent where problem centers lie, and less apparent where and how we should intervene even if we do happen to know what aims we seek". They further mention "waves of repercussions generated by a problem-solving action directed to any one node in the network", which may "induc[e] problems of greater severity at some other node" (p. 159). Seager, Selinger and Wiek (2012) present a condensed description (adapted from Norton, 2005) of these problems for the context of "Sustainable engineering science". In this thesis, these kinds of problems are called WSPs. In Paper I, however, the expression "complex challenges to SD" is used instead.

The first characteristic of WSPs as presented by Seager, Selinger and Wiek (2012) is related to the difficulty of problem formulation. The understanding of a WSP cannot be separated from the understanding of the solution to the problem since, as Rittel and Weber (1973, p. 161) point out, "every question asking for additional information depends upon the understanding of the problem – and its resolution – at that time". They conclude that "to find the problem is thus the same thing as finding the solution; the problem can't be defined until the solution has been found". This is a problematic notion for many students in engineering

who are used to being presented with precisely defined and described problem sets that they are required to solve. Second, there is no single right solution to these problems. Rather, there are multiple different ways of addressing the problem that are not always compatible with each other. Thus, addressing these problems requires actively choosing one way of addressing the problem over another. What choices are made depends to a large degree on the interpretation of what is to be sustained and developed in SD, and how sustainment and development are related to each other (section 2.1). Third, Seager, Selinger and Wiek (2012) describe time frames for WSPs as "open-ended". In other words, there is no one point in time at which the adequacy of a proposed solution is evaluated. A solution to a WSP may be favorable at one point in time, but highly problematic at another. For example, drastic measures could be taken today to halt the trend of global warming. Such an approach would be favorable if evaluated 200 years from now, but not everybody might agree that it would be favorable today if it would seriously harm the economy or disadvantage certain groups of people. This is related to different interpretations of the time scale that are considered appropriate for SD (section 2.1). Fourth, each WSP is novel and unique since each problem is embedded in a unique context. Thus, it is not possible to establish a "toolbox" with instrumental solutions from which to pick and choose appropriate solutions for each WSP. Rather, the unique context and nature of the problem need to be considered in every single case, and solutions need to be carefully developed on that basis. Finally, competing value systems and objectives exist for each problem, since problems and solutions concern multiple stakeholders who each have different interests (Seager, Selinger & Wiek, 2012). These characteristics of WSPs indicate the presence of powerful conflicts of interest. However, due to the ambiguity of the concept of SD, these conflicts are not always made explicit and may therefore be difficult for students to take into account unless they are adequately prepared to do so through their education.

3 The research context

Since SD is an important concept for the research presented in this thesis (section 2.1), the field of RESD provides a purpose and a direction for the research. In terms of theory and methodologies, however, the research is mainly rooted in the traditions of EER. Last but not least, the practice and research community of (R)EESD contributes an interdisciplinary platform for inspiration and exchange, and EESD practice provides concrete contexts for research and implementation. These different aspects of the research context have influenced which research questions have been asked in the context of the research underlying this thesis, and how these questions have been addressed. They are therefore explored in more detail in this section.

3.1 Engineering Education Research (EER) provides a theoretical and methodological backbone

EngE has a long history around the world. Originally, the purpose of EngE was to serve the needs of local small-scale industries and was carried out in the form of individual "hands-on apprenticeship" (Seely, 2005, p. 115) between a master and an apprentice. However, with the beginning of the industrial revolution, the nature of technological innovation changed dramatically and with it EngE, which became more science-oriented to live up to the industry's increased need of engineers who were able to work in an environment of a dramatically increased pace of innovation (Wankat, Felder, Smith & Oreovicz, 2002; Lohmann, 2008). Other driving factors for the development of EngE towards more scientific approaches have been military developments after World War II, and the space programs of the 1950s and 60s (Wankat, Felder, Smith & Oreovicz, 2002). More recently, the demands on EngE have again changed as the social context of engineering is starting to be recognized as important. Practical experience from working in the industry is yet again valued in engineering graduates' curriculum vitae. Graduates are also expected to have design skills and the ability to handle global complexity, diversity, sustainability issues, and stakeholder interests (Wankat, Felder, Smith & Oreovicz, 2002; Lohmann, 2008).

The EER field emerged out of the needs of engineering educators to better understand what characterizes high quality EngE and how to achieve it. Therefore, most EER is initiated on the basis of educators' strong ambitions to improve their own teaching, and it is conducted as undergraduate classroom research by engineering educators who themselves are formally trained as engineers. Most of these scholars are employed at engineering departments where their EER lies outside the "normal" research areas and is performed as an add-on when there is some free time available. The research typically deals with questions of immediate practical relevance such as how to increase diversity in engineering (e.g. women in engineering), how to attract the most talented students to study engineering, how to prepare students to meet the challenges of globalization, or more generally to achieve a deeper understanding of engineering learning in order to improve educational practice (Borrego & Bernhard, 2011).

More recently, EER departments, PhD programs, and professional societies are developing, and they offer a more solid platform for researchers to develop and discuss their research. With this trend comes a diversification of EER as the mainly practitioner-oriented and local

approaches (the Scholarship of Teaching and Learning, SoTL) are complemented with more theoretical, abstract and/or generalizable forms of research. The field is also characterized by an international diversity. For example, Borrego and Bernhard (2011) identify important differences between the Northern and Central European, and the US American approaches to EER. US researchers have recently called for changes in the ways EER is conducted in the country (for example Borrego, Douglas & Amelink, 2009, citing Creswell, 2002, and the Steering Committee of the (US) National Engineering Education Research Colloquies 2006). Borrego and Bernhard (2011) describe EER in Europe as predominantly driven by research questions, while research in the US is more often driven by a focus on accepted research methods for data collection and analysis. European researchers are also reported to predominantly focus on questions such as what should be the content and purpose of EngE, while US researchers often focus on how students learn in EngE, and what their measurable achievements are. US research is strongly influenced by stringent borders between disciplines and between departments, while EngE in Europe is expected to contribute to the students' personal development in a more holistic manner. The work presented in this thesis is based in the European tradition of EER, with a strong focus on "fuzzy" capabilities that are hard to measure and assess in for example multiple-choice tests, but it is also inspired by the Northern American notion of "rigorous research" (Borrego, Streveler, Miller & Smith, 2008), which stresses the need to adopt a scientifically sound approach.

3.2 Research in Education for Sustainable Development (RESD) provides a direction and purpose

RESD is a relatively new and "rather young and unorganised" (Reunamo & Pipere, 2012) research field. It focuses on learning about and for SD, which itself is a relatively new concept as described in section 2.1. As such, RESD is not yet a mature research field, and metamethodological, epistemological and ontological debates have only started to emerge during the last one or two decades (Hart & Nolan, 1999).

RESD has its roots in environmental education research (EnvER), which in contrast to EER is often concerned with education on the elementary school level. The research interest in EnvER originated in an increased environmental awareness in the 1970s and a realization that education plays an important role in dealing with the increasing environmental challenges that are caused by resource depletion and pollution. Initially, EnvER mainly focused on measurable effects of environmental education (EnvE) activities. At that time, quantitative approaches were often used with the goal to find ways of rendering EnvE practices more efficient in terms of behavioral change that would cause students to more consequently act according to ambitions to protect the environment (Palmer, 1998, in Hart & Nolan, 1999).

In 1999, Hart and Nolan noticed that EnvER was starting to become more diverse in terms of underlying ontologies and epistemologies: "environmental education research can now be characterized as engaging positivist, interpretivist/constructivist, critical and feminist/postmodernist perspectives. Each of these approaches and their diverse intersections view epistemology and ontology differently." They further cite Elliott (1993) who states that "there has been a shift from an objectivist view of knowledge to views that regard knowledge as more provisional, problematic, and socially constructed". Along with this increasing

diversity of research approaches also came an increasing focus on qualitative methodologies since the 1990s (Hart & Nolan, 1999, p. 36).

However, Hart and Nolan (1999, p. 39) were concerned about the quality of research in these emerging approaches:

> *"Given the increase in 'alternative conceptions' types of studies (Wandersee, Mintzes & Novak, 1994), as well as those that combined methods of data collection, and a general shift away from strictly positivist approaches, we were concerned with the trustworthiness and authenticity of the accounts (Guba, Guba & Lincoln, 1994). For the smaller but growing number of studies from within the tradition of critical or postmodern theory we were concerned with the representativeness of the accounts".*

Hart and Nolan (1999, pp. 39-40) supported the then recent development of metamethodological debates in EnvER. They drew on Gerber (1996) in urging educators who want to engage in EnvER to read more widely about "qualitative research methods, philosophy, epistemology, and ontology". They also drew on Payne (1999, p. 40) as they advocated a stronger engagement in "deliberate self-critical appraisal of their [the educators'] role and the meaning of their results based on their own value commitments and beliefs, sociocultural location, and ontology".

As discussed in section 2.1, the concept of SD emerged in the 1990s. At the time, some EnvE researchers suggested a new terminology for the field, in which "environment" would be replaced by "SD" (Hart & Nolan, 1999, p. 19). These scholars argued that ESD offers a broader focus, as both environmental, social, and economic aspects are considered (e.g. Tilbury, 1995). As some researchers focused on ESD rather than EnvE, RESD was gradually developed as a more or less independent research field. Until today, however, the appropriateness of ESD is debated as some scholars maintain that ESD actually offers a more limited focus than EnvE. Their argument is that ESD is based on SD as a political concept that accepts the existing paradigm of market economies and presents education "as an instrumentalist and ideological tool" (Jickling, 2003, p. 21). These scholars see ESD as politically guided and non-critical, as opposed to EnvE, which they describe as having a strong tradition of social critique. Such critique, they argue, is crucial for protecting the environment against the destructive powers of conventional economic systems (see McKeown & Hopkins, 2003, for a comparison of EnvE and ESD). In practice, however, it is unclear whether these differences among the fields are as strong as suggested (Jickling & Wals, 2012). For example, ESD researchers may be aware of the problematic nature of SD as a political concept (e.g. Jickling & Wals, 2012), or they may see social critique as part of ESD (e.g. Tilbury, 1995). Further, Monroe (2012) provides examples of EnvE initiatives in which the need to include social, economic, technological, political and ethical aspects in order to be able to contribute to the resolution of environmental problems is recognized.

McKeown and Hopkins (2003) suggest that disputes about terminology may be fruitless and actually hinder the goals of both fields. They call for local collaborative action among educators and researchers who want to see a change towards stronger environmental

protection and increased human well-being. Wals adds that different terms might provide more powerful frameworks than others, depending on the local political and cultural climate. For example, EnvE may be a more generative framework in areas where the EnvE movement is strong and functional. In other areas, ESD may serve as a "bridging term that makes it easier for those who haven't considered these issues before to become engaged". Wals adds, "what is actually done on the ground in terms of teaching and learning is more important than the label under which these activities and actions take place" (Jickling & Wals, 2012, pp. 52-53) (see also Monroe, 2012). For this thesis, ESD is seen as a necessary focus in EngE, but also as a more powerful concept than EnvE, since EngE is experienced to generally neglect social and political aspects at the expense of technological and environmental questions that are more easily accessible with instrumental and facts-based approaches to education. These approaches are perceived to still be common practice in EngE.

Apart from ESD, several other labels with similar connotations are used in the field, such as "education for sustainability (EfS), education for a sustainable future (ESF), environmental and sustainability education, sustainability education (SE)" (McKeown & Hopkins, 2003, p. 214) or "environmental education for sustainability (EEFS)" (Tilbury, 1995). Only time will tell which of them will emerge as the dominant label. In this thesis, ESD is used exclusively, not because of a preference of the particular connotations that it carries, but because it is experienced as the most accepted and most widely used term in the field today. A notable example is the use of the term by the United Nations Educational, Scientific and Cultural Organization, who declared a decade of ESD for the years 2005-2014 (UNESCO).

Reunamo and Pipere (2012) suggest that RESD needs a combination of theoretical, philosophical, quantitative and qualitative research. In a field that is highly interdisciplinary and engages researchers from diverse backgrounds, such as the educational sciences, natural sciences, social sciences, and humanistic sciences (Reunamo & Pipere, 2012), the potential for diverse and mutually complementary research initiatives is high. Indeed, Reunamo and Pipere (2012, p. 314) note the "emergence of a large array of diverse perspectives, approaches and understandings of ESD". However, a brief and unstructured review of the latest numbers of three prominent journals in the field (Journal of Education for Sustainable Development, International Journal of Sustainability in Higher Education, and Journal of Sustainability Education) suggests that this potential may not be fully utilized today, since much work in the field seems to comprise educators' accounts of their experiences from ESD-initiatives that they have started on the basis of strong personal beliefs. This is in line with Reunamo and Pipere's (2012) findings that many ESD researchers share a strong commitment to use ESD to contribute to SD in one way or another. While this dedication among researchers gives momentum to the field, it may also divert attention from methodological issues and meta-level discussions. In addition, it may fuel critics' concerns about ESD as serving predefined political agendas (section 2.1). A stronger focus on empirically analytical and theoretical studies might benefit the field and raise the quality and influence of ESD research while preserving the strong sense of purpose that distinguishes this research field from many others.

3.3 Research in Engineering Education for Sustainable Development (REESD) provides a platform for inspiration and exchange

Research in REESD is in this thesis seen as the interface between EER, RESD and EESD. The European REESD community involves both practitioners (engineering educators) and researchers, some of whom participate in biannual conferences on EESD. Most researchers in REESD have a background in engineering rather than in the educational sciences. Their interest in EESD is usually spurred by their practical experiences as engineering educators trying to incorporate some elements of ESD into their teaching. Similar to researchers in the field of RESD, they are often highly motivated to use ESD to contribute to SD. To them, REESD offers a venue for developing a more scholarly approach towards their own practice, and a platform for exchange with other EESD practitioners. In the biannual EESD conferences, the following issues have been the main foci throughout the past decade (adapted from Mulder, Segalàs-Coral & Ferrer-Balas, 2010):

1. Research related to the practice of EESD:
    - Content of EESD
    - EESD processes: Active learning and project based learning in EESD
    - The role of external stakeholders for EESD at technical universities
    - EESD as a normative endeavor in an academic context
    - Assessment in EESD

2. Research related to the implementation of EESD:
    - Campus engagement for SD
    - Top-down versus bottom-up approaches to institutional change
    - Ways of engaging engineering faculty in EESD
    - Curriculum change as the creation of new educational programs versus changes to existing programs

The interdisciplinary nature of REESD poses serious challenges to researchers as they attempt to develop competencies to conduct rigorous research on an academic level, particularly for practitioner researchers who have a limited amount of time and resources at disposal to immerse themselves into REESD. Therefore, EER rather than REESD has been chosen as the theoretical and methodological context for this PhD project. Still, the (R)EESD community and the biannual EESD conferences play an important role as a meeting place for mutual inspiration and for sharing and testing ideas related to both EESD and REESD.

4 Methodological considerations

4.1 Methodology in EER

As discussed in section 3.1, EER is an emerging field of research. Common for EER around the world is that, since most researchers have a background in engineering rather than social or educational sciences, they bring with them the philosophical assumptions from the field of engineering. Jawitz and Case (2009) present an overview of common theoretical positions that might be useful for EER. These are *positivism*, which provides a framework for hypothesis testing, mainly in the natural sciences and in engineering; *constructivism*, which is guided by research questions and allows researchers to develop new ways of understanding and making sense of phenomena; and *critical theory*, which enables researchers to critique social structures with the aim to reduce power imbalances. Jawitz and Case (2009) argue that a background in engineering may lead to an uncritical adoption of positivistic perspectives in EER. They stress that such perspectives are useful for some research, but not sufficient as the *only* framework in EER. They appeal to EngE researchers to become aware of, and make explicit, the theoretical frameworks that they use in their research, and to consider alternative frameworks. Bernhard and Baillie (2012, p. 1) add to this discussion by "maintain[ing] that a mere unquestioning acceptance of one research paradigm, or epistemology, which is usually the dominant paradigm, can lead to inappropriate matching of research questions to methodologies, confusion between reliability and validity, and a lack of transparency of the criteria being applied with respect to what constitutes research quality".

According to Bernhard and Baillie (2012), partly drawing on Borrego and Bernhard (2011), high quality research in EER is characterized by a high level of epistemological awareness, i.e. an awareness of what is meant by concepts such as "learning" and "knowledge". This may be particularly important in an emerging field such as EER, where widely accepted traditions and cultures have not yet evolved. Bernhard and Baillie (2012) also stress the importance of an adequate grounding in, and contribution to, practice, while at the same time contributing to theory development. They further suggest that research should be performed in a systematic and intentional way, irrespective of which research methodologies are applied.

Historically, quantitative approaches have been favored in EER, partly due to an experienced need to prove the validity of the research to engineering faculty (Bernhard & Baillie, 2012). Borrego, Douglas and Amelink (2009) argue that EngE researchers intellectually understand and reiterate the value of more qualitative research, but that they still seem to struggle to fully embrace related research paradigms and to judge research accordingly, possibly because they lack the knowledge and experience to judge the quality of this kind of research:

> *"Observations at an international engineering education research conference uncovered a strong preference for quantitative methods and their associated evaluation criteria, likely due to most participants' technical training. While participants lamented a lack of reviewers' acceptance or understanding of qualitative work, the same participants enacted a quantitative, classroom-experimental model in critiquing each others' work"* (Borrego, Douglas & Amelink, 2009, pp. 53-54; see also Box 1).

Since philosophical assumptions are manifested not only in the methodologies used, but also the kinds of questions that are possible to address, Jawitz and Case (2009) express support for stronger consideration of constructivist and critical perspectives in EER. Such perspectives might facilitate the understanding and adoption of more qualitative research approaches in EER. Case and Light (2011) introduce a number of such qualitative research methodologies that are "emerging" in EER, i.e. they are seen as carrying potential for powerful EER, but as not yet well established in the international EER-community. These emerging methodologies are case studies, grounded theory, ethnography, action research, phenomenography, discourse analysis and narrative analysis. A phenomenographical approach is used in Paper II in this thesis.

Box 1: Reflections on the influence of personal background[1]

The above quote by Borrego, Douglas and Amelink (2009) *resonates well with my own experiences from becoming an EngE researcher after having gone through undergraduate and master's training in engineering nanotechnology. Like many other researchers in the field, I started out with a profound interest in improving EngE practice. This interest first led me to engage in the creation and teaching of an SD course for undergraduate students in the engineering nanotechnology program. As I was confronted with the difficulties of ensuring that the course functioned in the way that we had intended, I started to look at our practice from a more scholarly perspective. I was greatly inspired by what I learned from other teachers' experiences*, *and I decided that I wanted to pursue a PhD in the field. Throughout my PhD education, I am continually reminded of my background in engineering as I (and others) catch myself falling back into more reductionistic and positivistic ways of thinking about my research – despite my strong convictions that the topics I investigate should be approached with an interpretative mindset. I apply qualitative methodologies, but I have to constantly watch myself to ensure that I do not attempt to use them in reductionistic ways. I need to ensure that I do not only succeed in creating the neatest possible categories and models, but also in capturing and describing the deeper meaning of the material that I work with.*

4.2 Strategies for bridging gaps between research fields

As described in section 3, the research presented in this thesis is situated in the field of EER, it draws on RESD, and it is connected to both research and practice in EESD. This results in a highly interdisciplinary context, which requires careful attention to underlying philosophical assumptions. Today, these assumptions are not always made explicit in EER (Jawitz & Case, 2009), nor in RESD (Dillon & Wals, 2006; Tilbury, 2011). The situation is further complicated by the fact that ESD is not yet comprehensively included in EngE around the

[1] In some parts of this thesis, personal reflections about the research process are included. These are presented in italized text and enclosed in boxes. The purpose of these reflections is to help the reader to better understand the background for the research presented in the papers and the thesis and to be able to form his/her own understanding of the transferability of these findings to other contexts.

world, which makes EESD appear as an odd fellow in the eyes of many EngE researchers and practitioners. Consequently, researchers in EESD need to navigate tensions that are created by the sometimes hidden differences between and within the fields of EER and RESD.

As stated in section 1.2, two of the general aims of this PhD project are to improve the integration of EESD in EngE and of REESD in EER, and to facilitate communication between research and practice in EESD by attempting to overcome some of the above-mentioned tensions. In this PhD project, these aims are approached indirectly by choosing research questions and methodologies that may appear meaningful to the different groups. Basic philosophical assumptions that underpin a research project may influence the researcher's ability to effectively communicate across different disciplinary fields. As Jawitz and Case (2009) point out, the default theoretical position in engineering is often positivistic with a focus on testable hypotheses and a view of research as neutral and detached. Some ESD researchers, on the other hand, are more accustomed to critical and collaborative research approaches (Hart & Nolan, 1999) that explicitly aim at changing existing power imbalances in society. In this thesis, a mainly constructivist approach has been chosen as a potential middle ground between these two groups, since constructivist research is neither assumed to be detached, nor politically active.

The choice of research methodology is related to these fundamental theoretical assumptions, and can further influence whether different groups of people can find the research meaningful. For example, engineering faculty is generally not very familiar with qualitative research approaches, and may distrust the findings generated in this kind of research (Borrego, Douglas & Amelink, 2009), while the above mentioned "critical" ESD researchers may struggle to see the value of purely instrumental and quantitative methodologies. A phenomenographic approach, as it is applied in the research underlying Paper II, may provide a middle ground for these two groups. The engineers may be able to trust phenomenographic results since they are generated in a strictly empirical way; the critical ESD researchers may find the results valuable since they provide rich descriptions based on qualitative data, and since they have a strong relationship to educational practice rather than being presented as objective knowledge. However, phenomenographic research also involves rather complex theoretical assumptions that require a certain level of familiarity with the methodology in order to be able to use the results in a meaningful way. Thus, the researchers may need to devote more time and effort to create closer connections between the theoretical results and practical educational applications if they want to engage practitioners in discussions about, and implementations of, the research. This presents a remaining challenge for this PhD project.

Last but not least, the way in which research results are presented may influence how accessible they are to different groups of researchers. In this thesis, graphical models and tables have been used to represent findings in a way that may appeal to engineers. At the same time, rich descriptions and concrete empirical examples have been used to increase the value of the representation for researchers who mainly work in a qualitative and interpretive manner. It might be valuable to complement these ways of presenting research results with more popular scientific approaches that are directed towards EESD practitioners.

4.3 Considerations concerning Paper I: Perspectives as a sensitizing concept

In 1954, American sociologist Herbert Blumer laments a "[glaring] divorcement [of the research field of social theory] from the empirical world" (p. 3). Blumer (1954, pp. 4-5) continues: "Theory is of value in empirical science only to the extent to which it connects fruitfully with the empirical world. Concepts are the means, and the only means of establishing such connection, for it is the concept that points to the empirical instances about which a theoretical proposal is made. If the concept is clear as to what it refers, then sure identification of the empirical instances may be made. (…) With clear concepts theoretical statements can be brought into close and self-correcting relations with the empirical world. Contrariwise, vague concepts deter the identification of appropriate empirical instances, and obscure the detection of what is relevant in the empirical instances that are chosen. (…) They do not permit a determination of what is covered by the concept and what is not". This ambiguous nature of concepts in social theory, Blumer (1954, p. 7) argues, "leads to the undisciplined theorizing that is bad theorizing".

Blumers reflections on the importance of clear concepts as a basis for empirical research resonate with the critique depicted in section 3 of the fields of EER, RESD and REESD as lacking in metamethodological considerations and rigorous empirical research. It also resonates with the difficulties that were encountered at the beginning of this PhD project (see Box 2). Without a theoretical or philosophical basis to build on, how could one formulate precise and explorable research questions?

As indicated in section 1.1, the initial inspiration for the research that is presented in this thesis comes from Wals and Blaze Corcoran's (2006) description of four dimensions of perspective shift that they see as necessary for transformative learning in ESD: transgenerational, transnational, transcultural, and transdisciplinary shifts. However, as discussions about the concept of perspective shift evolved during the early phases of this PhD project, the ambiguity and vagueness of the existing descriptions became apparent. For example, the term perspective may be used to describe a physical viewpoint as in "aerial perspective", which denotes a position above the object that is viewed from this perspective. A perspective shift would then entail a changing physical position relative to this object. The term perspective may also be used in the meaning of "worldview", which entails specific philosophical assumptions about the world rather than a physical position. A perspective shift in this sense would mean a radical reinterpretation of the world by a certain individual or group. In drawing and sketching, the term perspective is often used to describe a technique of representing three-dimensional objects on a two dimensional medium. In this case, perspective shift might indicate a different vanishing point. Clearly, the perspective shifts described by Wals and Blaze Corcoran (2006) are not in accordance with any of these conceptions of the term perspective, but there is no alternative description provided in the RESD or REESD literature either. Without such a conceptual basis of what is meant by "perspective shift" or even "perspective" in the context of REESD, empirical investigations related to the concept were deemed to be impossible without further clarification of what is meant by "perspective shift", or even "perspective" in the context of REESD, since it was impossible to identify a suitable starting point and focus for such research.

Chamaraz (2003) (in Bowen 2006, p. 259) picks up on Blumer's term "sensitizing concepts", which Blumer defines as "those background ideas that inform the overall research problem". Perspectives in this PhD project can be understood as such a sensitizing concept, which offers a "[point] of departure from which to study the data" and "suggest[s] directions along which to look" (Blumer, 1954, p. 7). A clear definition of the concept of perspectives in EESD is thus not an end in itself (c.f. Padgett, 2004, in Bowen, 2006). Rather, the meanings that are developed in Paper I offer a conceptual platform and thus a starting point for further research. The concept may subsequently be refined, redefined, or evolve into different concepts that are more useful for research in (E)ESD (Box 2).

Box 2: Reflections on guiding concepts in research

When I started my PhD studies, I felt as if I was in a constant state of "limbo" (research diary 2011-09-29), of being "stuck" (research diary 2011-09-12). I started reading about all sorts of concepts in EESD: creativity, threshold concepts, EESD competencies and pedagogies, motivation, critical thinking, sustainability, etc. I felt as if I was drowning in a sea of endless possibilities for research – while at the same time being unable to actually identify a concrete starting point.

Six weeks into my studies, I met with my supervisors, who tried to help me to focus my thinking:"We (...) talked about my project and managed to identify a FOCUS (perspective shifts), a goal that I can aim towards and which can provide that structure that I long for. (...) It felt as if I've finally 'started'" (research diary 2011-09-29, translated from Swedish). Initially, the sense of having such a guiding concept helped me to structure my thoughts.

However, as I kept thinking about the concept [perspective shift], I realized how ambiguous and underdefined it is as a background for empirical research:"I've (...) been thinking a lot about perspective shift lately, and I've tried, once again, to understand what I actually want to get at with my research. Exactly what is it that I think the students should be able to do? What is this competence and how should it be defined when it comes to what is ethically sound, what is reasonable, what is important, ...? (...) And is perspective shift really the right focus? Isn't it critical thinking instead? Critical consciousness? An ability to 'rethink'? Reconceptualize? Deconstruct? Ask relevant questions?" (research diary 2012-01-30, translated from Swedish).

Throughout my studies, I continued to doubt whether perspective shift was the "right focus". In fact, I still do. But whatever the answer to this question is, the concept has provided a useful direction for my research.

4.4 Considerations concerning Paper II: Phenomenography of complex phenomena

Phenomenographic research aims to describe various ways in which people experience specific phenomena in the world, with the explicit aim to provide a theoretical basis on which to improve educational practice (Marton & Booth, 1997). Since the initial phenomenographic studies on students' conceptions of learning in the 1970s, which resulted in the widely

adopted theory of deep and surface learning (e.g. Marton & Säljö, 1976a; Marton & Säljö, 1976b), a variety of different phenomena have been investigated with a phenomenographic approach. In the field of EER, for example, Johansson, Marton and Svensson (1985) have studied students' conceptions of force. More specifically disciplinary concepts have also been investigated in the context of EngE, such as the concepts of object and class (Eckerdal, 2009) and specific network protocols in computer programming education (Berglund, 2005). The studies by Case and Marschall (2004), who expand on the original phenomenographic studies by Marton & Säljö, provide examples of more general studies on student learning in EngE. Some of these concepts, such as those studied by Berglund and Eckerdal, allow the researchers to work with rather well-defined phenomena for which scientifically accepted ways of understanding exist. The concept of learning, on the other hand, is more complex and a widely accepted definition of what the "right" way of understanding this concept may never be established. The phenomenon that is the focus of the study described in Paper II has a similarly high level of complexity. In this section, a number of aspects of this complexity are described and discussed in terms of their relevance for methodological considerations in this study.

As described in Paper II, the phenomenon in the study evolved in the interview situation in relation to three different contexts: the interview context, which included a problem description and six solution alternatives; the problem context, which was dependent on the participants' previous experiences related to the given problem; and the educational context, which was characterized by a tension between traditional engineering education and a more unconventional course on sustainable development. The simultaneous presence of these three contexts indicates a high level of complexity of the phenomenon. Another factor that increased the complexity of the phenomenon is the ambiguous and contested nature of the concept of SD as discussed in section 2.1. Students' different conceptions of SD may influence their understanding of the phenomenon if the phenomenon were targeted directly with questions such as "What are complex sustainability problems?" Such questions might also cause participants to focus on the *term* "complex sustainability problems", or possibly "sustainability", both of which were not the intended phenomena in this study. Therefore, an indirect approach has been chosen, in which the participants were actively engaged in a discussion about a concrete WSP, and their conceptions of the phenomenon were analyzed on the basis of how they related to the problem and to possible ways of dealing with it. Unfortunately, such an indirect approach adds an extra level of interpretation to the analysis of the empirical material and thus further increases its complexity.

Such an unruly, straggling material presents a serious challenge to the researcher (see for example Box 3) since it becomes more difficult to hold all aspects of the participants' ways of experiencing the phenomenon in mind simultaneously, to be aware of the meaning and structure of these ways of experiencing, and at the same time to analyze the ways in which they are similar to, or different from, each other. In their seminal work *Learning and Awareness*, Marton and Booth (1997, p. 133) describe the task of a phenomenographic analysis as follows: "All of the material that has been collected forms a pool of meaning. It contains all that the researcher can hope to find, and the researcher's task is simply to find it". However, since the mental capacity of even the brightest researchers is limited, a higher level

of complexity in the material necessarily requires a higher level of reduction and simplification in order to allow the development of a powerful and useful outcome space. Thus, what can be "found" in the material is likely to have a different character if the phenomenon is complex than if it is well defined. In particular, a higher level of abstraction is needed to make sense of the data by reducing the complexity of the phenomenon and thus enabling the researcher to produce neatly organized categories. This approach is in many ways reductionistic and goes against the idea of SD as introduced in section 2.1. A trade-off is necessary between providing descriptions that are high in explanatory power versus rich descriptions that more adequately represent the nature of the phenomenon. An additional issue is the stronger alienation from educational practice that comes with increasing levels of abstraction, and thus a greater need for translation between research and practice as indicated in section 4.2. A specific and explicit approach to abstraction may be the use of theoretical concepts from the literature to structure the analysis of the empirical material. However, as Åkerlind (2005, p. 323) points out, care must be taken to avoid a premature closure in the analysis due to these introduced structures: "Paramount is the importance of attempting, as far as possible, to maintain an open mind during the analysis, minimizing any predetermined views or too rapid foreclosure in views about the nature of the categories of description. The researcher needs to be willing to constantly adjust her/his thinking in the light of reflection, discussion and new perspectives".

Box 3: Reflections on the challenging task of phenomenographically analyzing a complex material

When I started to work with the empirical material in a structured way, I was confident and filled with a sense of anticipation. I thought that the framework of phenomenography would provide a great structure that would make the analytical process rather straightforward. How wrong I was! As soon as I started cutting my transcripts into fragments of meaning, my trouble started and I was overwhelmed with the complexity of the material, the phenomenon, the many facets of meaning captured in each of the fragments, … I covered the entire office with paper snippets, post its, colored markers and, drawings on whiteboards, windows, and scrap paper. I whined to my colleagues, supervisor, and friends about not knowing what to do with the material: "I'm a little bit stuck in the phenomenographic analysis and don't quite know how to proceed. The material is just exploding before my eyes…" (email to supervisor 2013-08-26). While I still enjoyed the process, I sometimes felt that I should just give up and start over again with something simpler and more accessible.

Finally, the complexity of a phenomenon also has an impact on the design of the research study. The more complex, flexible, and undefined a phenomenon is, the more care must be taken to ensure that the material actually provides a basis for analyzing conceptions of the intended phenomenon. Still, it is not possible to assume that the actual phenomenon that is constituted in the research situation matches the intended phenomenon. Thus, the researcher needs to pay close attention to identify the emerging phenomenon during the analysis phase of the research. This is the reason for the extensive description of the phenomenon in Paper II. Last but not least, it is also harder to ensure that the material provides a complete basis for identifying all possible ways of understanding the phenomenon. Consequently, single studies

of complex phenomena may not always provide complete results, and they may need to be expanded upon and complemented with further studies.

4.5 Methodological comparison of the included papers

Both of the papers that are included in this thesis are based in the context of EESD. The papers differ in their methodological approaches (conceptual in Paper I and empirical in Paper II), but they share some important assumptions about the nature of knowledge and understanding. Most importantly, they share a relational view of understanding. In Paper I, this assumption is represented in the descriptions of perspectives as constituted by a relationship between a person (an actor) and an object, which is the focus of the actor's attention (Paper I, p. 7). Neither the object nor the actor are thus of direct interest. The paper does not provide a better understanding of the nature of SD challenges as objects, nor does it describe characteristics of students in EESD as actors. Rather, the attention is directed towards the ways in which the students interact with complex sustainability challenges.

In Paper II, a phenomenographic research approach is used which takes this relational nature of understanding as one of its main premises (Marton & Booth, 1997, p. 122). As described in section 4.4, the phenomenographic researcher tries to identify distinct conceptions of, or ways of understanding, a specific phenomenon. Again, it is neither the phenomenon itself nor the experiencers' (students') internal reality that are of interest, but the ways in which the students relate to the phenomenon. In the students' engagement with the phenomenon, meaning is created, and it is this meaning, along with the structure of the students' ways of understanding, that is the main interest of phenomenography.

Students may switch between different conceptions (Marton & Booth, 1997, pp. 132-136), but they can never hold more than exactly one conception of a phenomenon at any time. In other words, conceptions are constructed to be parsimonious and mutually exclusive, and the set of possible conceptions is experienced to be limited (Marton & Booth, 1997, in Pang, 2003, p. 323). Further, since it is impossible to "describe experience in its entirety", phenomenographic researchers "are constrained to look for and describe critical differences in people's capabilities for experiencing the phenomena in which [they] are interested" (Marton & Booth, 1997, p. 123). In other words, the focus of a phenomenographic analysis is not on describing different ways of experiencing a phenomenon as completely as possible, but rather to highlight differences between these conceptions. In particular, educationally critical differences, i.e. differences that are important for learning to experience a given phenomenon more fully, are of interest. These differences are described in terms of the different meanings that underlie the respective ways of experiencing the phenomenon, as well as differences in the structure of these ways of experiencing (Marton & Booth, 1997, p. 87). Since the conceptions are constituted by the similarities and differences between them, they can only be assumed to exist in relation to each other and the total pool of meaning that is created by the entire empirical material. Thus, conceptions are inevitably related to each other in a logical and often hierarchical structure (Marton & Booth, 1997, pp. 124-128). In Paper II, four such conceptions of a phenomenon related to a WSP are described, that have been constructed on the basis of an empirical analysis (pp. 8-17).

Table 1. Summary of similarities and differences in philosophical assumptions and the nature of the results in Paper I and II.

	Paper I	**Paper II**
Non-dualistic assumptions	A perspective is constituted by a relationship between an actor and an object	A conception/way of understanding is constituted by a relationship between a student and a phenomenon
Object of focus	Complex sustainability challenges as a general class of objects	The specific phenomenon that is created in the interview situation
Research approach	Conceptual modeling	Empirical analysis based on a phenomenographic approach
Role of empirical data	Sounding board and illustrative examples	Bearer of conceptions that are expressed in the transcribed interviews
Analytical approach	Identify concepts that are relevant for describing perspectives in the context of EESD	Identify educationally critical differences between ways of experiencing a specific phenomenon
Type of results	Concepts that describe characteristics of perspectives and perspective processes in terms of continuous variables	Categories that describe the meaning and structure of distinct conceptions
Nature of concepts/ categories	Concepts may overlap and can be combined to provide complementary and logically coherent descriptions of different perspectives	Categories are mutually exclusive, parsimonious, and logically (often hierarchically) related to each other
Implications for perspectives/ conceptions	Unlimited number of different perspectives possible	A limited number of conceptions is possible for a given phenomenon

In Paper I, a conceptual model is described, that is not based in an empirical analysis. Instead, the empirical material was used as a sounding board and as a source of illustrative examples for the description (Paper I, p. 6). The concepts that are included in the model cover both characteristics of perspectives and perspective processes. In contrast to the conceptions that are described in Paper II, these concepts are neither assumed to be mutually exclusive, nor are they unambiguously defined. Their value does not lie in their clear definitions and demarcations against other concepts, but in their usefulness in the context of (R)EESD (Paper

I, p. 3-4; Section 4.3). As a result, these concepts are continuous variables, such as depth and coverage of perspectives, and they are assumed to provide logically cohesive descriptions of perspectives and perspective processes that enable researchers and practitioners to describe different kinds of perspectives. Thus, in theory, it is possible to describe an unlimited number of different perspectives with these concepts.

Table 1 summarizes some important similarities and differences in the philosophical assumptions and the nature of the results in the two papers, and provides a basis for an integrative description of the research results in section 5.

5 Results

In this section, five questions that have emerged on the basis of results of Paper I and II are addressed by integrating the conceptual framework provided in Paper I and the empirical results presented in Paper II.

5.1 What indicates students' engagement with a problem?

Paper I describes the process of developing an understanding of the problem as *perspective formation*, which "occurs when an actor first becomes aware of an object (…) [It] is the most fundamental process [in the model in Paper I] (…). In the context of SD, perspective formation is a prerequisite for becoming aware of a particular challenge, its relevance for SD, and possible ways of addressing it" (p.10).

Perspective formation in relation to a WSP, then, may be seen as a basic prerequisite for dealing with the problem in an actively and profoundly engaged way. It is not possible to address a problem such as water shortage in Jordan without acknowledging the complexity of the situation and taking responsibility for managing it in a constructive way. In Paper II, the category *simplify and avoid* indicates that students holding this conception may lack a strong sense of engagement with the problem. They talk about solutions and problems in inarticulate and inconcrete ways and their conceptions lack both a deeper meaning and a clear structure.

5.2 What is a complex understanding of WSPs?

In both papers, the complexity of students' ways of relating to complex sustainability problems is addressed. In Paper I, a high level of complexity of students' perspectives is described as reflecting an understanding of the presence of relationships between individual aspects of a sustainability problem. The terms "holistic perspective" and "systems view" are used in this context. *Complexity* is introduced as a concept that may be used to describe perspectives in a way that is considered meaningful for SD since "[a perspective with a high level of complexity] can for example be useful for avoiding rebound effects of technological development (…) that may arise when behavioral and other social systemic responses to new technology cause an exaggeration of the original situation, despite the technology's apparent contribution to an increased efficiency on the local scale of the isolated technology" (p.9).

In Paper II, the interest in the complexity of the students' ways of understanding the given problem is inherent in the phenomenographic research approach. The systematic focus on the complexity of different ways of understanding a phenomenon that is offered by such an approach enables a more nuanced understanding of how a complex understanding may be structured, expressed, and applied, which in turn complements the description of complexity offered in Paper I. An interesting observation from the description in Paper II is that there may be a mismatch between the level of complexity of a students' understanding of the different parts of a phenomenon. In the category *isolate and succumb* for example, the problem is understood as a complex system of interrelated parts. At the same time, the solution – if it were possible to find it – is still expected to consist of several independent and isolatable parts that can be added together without integration. Figure 1 illustrates this mismatch and contrasts it with the understanding of the problem and the solution in *integrate*

and balance, where both problem and solution are understood as systems of interconnected parts. A solution is in this conception not understood as something that solves, and thus eliminates and replaces, the problem. Rather, a solution is experienced as consisting of a number of problem management strategies, i.e. the parts of the solution, that are integrated and interact with the different aspects of the problem. Consequently, in *integrate and balance*, the students' understanding is complex in relation to the whole phenomenon, while in *isolate and succumb* it is only complex in relation to the part of the phenomenon that is constituted by the problem. In general, the complexity of perspectives increases from conception *simplify and avoid* to *integrate and balance* as indicated in figure 2.

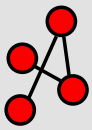
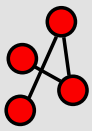
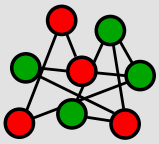
View of the structure of the problem	View of the structure of the solution	Conception
		C: Isolate & Succumb
		D: Integrate & Balance

Figure 1. Participants' views of the structure of the problem and the solution in two of the categories in Paper II. Red circles indicate problem parts, green circles indicate solution parts. In conception D, the view of the solution includes both parts of the problem and parts of the solution.

In conclusion, a perspective may be seen as constituted by a number of parts, i.e. different ways of relating to different parts of the object of focus. The complexity of such a perspective, then, is not necessarily a characteristic of the whole perspective, but may differ between the parts of the perspective.

5.3 How are perspective coverage and complexity of understanding related to each other?

As described in section 5.1, the least complex conception that is described in Paper II, *simplify and avoid*, indicates naïve and superficial engagement with the phenomenon. However, according to the terminology in Paper I, students with this conception may well express considerable perspective coverage as indicated by "the number and variety of aspects considered in relation to the specific object. The more extensive the range and diversity of covered aspects, the broader is the coverage of the perspective" (p.8). Students who hold the conception *simplify and avoid* may well talk about a variety of aspects of the problem, but they may do so in an unspecific and superficial way. Thus, *coverage* represents a characteristic of perspectives that is not necessarily related to the *complexity* of the corresponding conception. This observation is illustrated in figure 3, which is adapted from a

figure that summarizes the structural aspects of the different conceptions in Paper II. Both parts of figure 3 are a representation of the category *simplify and avoid*, but the different sizes of the circles indicate a difference in perspective coverage within this category. Larger perspective coverage within the category simply provides a broader, but equally diffuse, focus on the phenomenon.

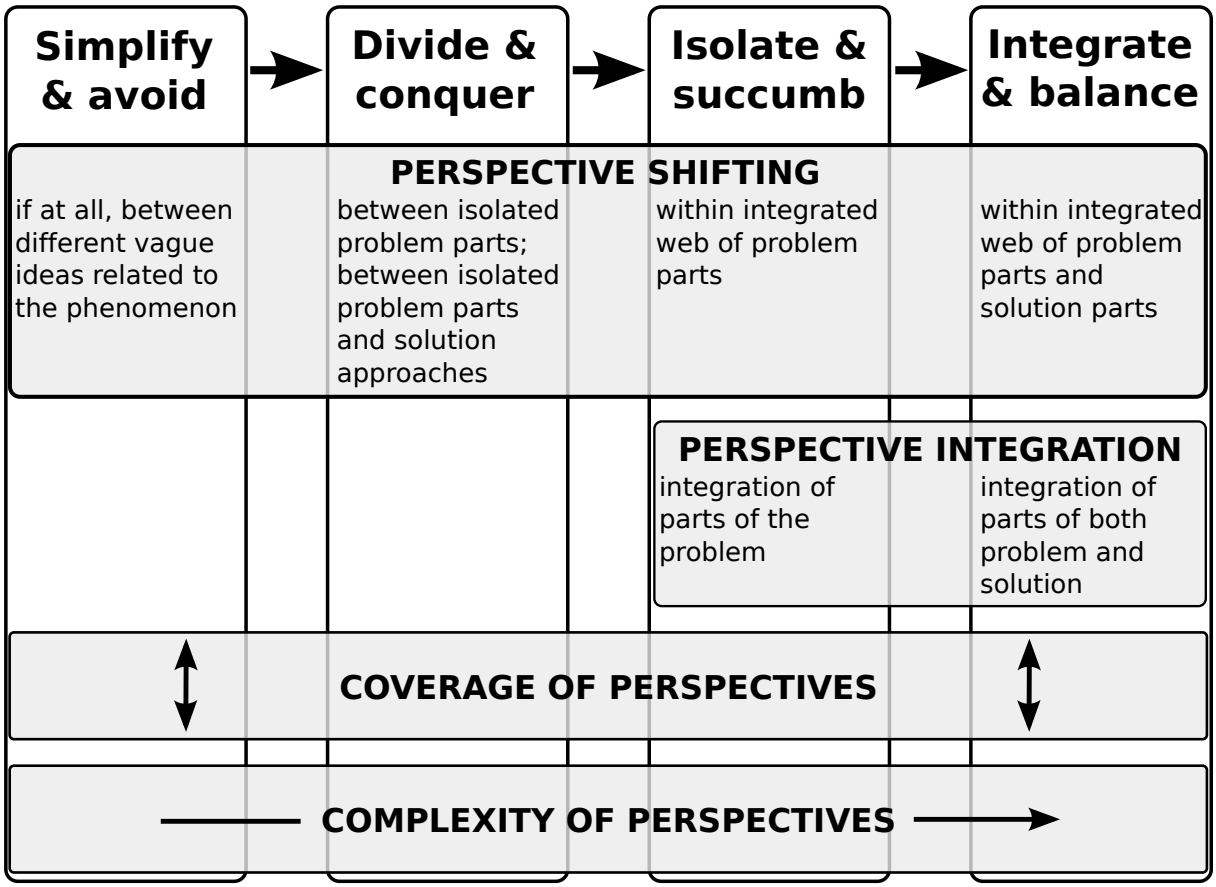


Figure 2. Summary of the concepts used in Paper I (grey background) and 2 (white background), and how they relate to each other.

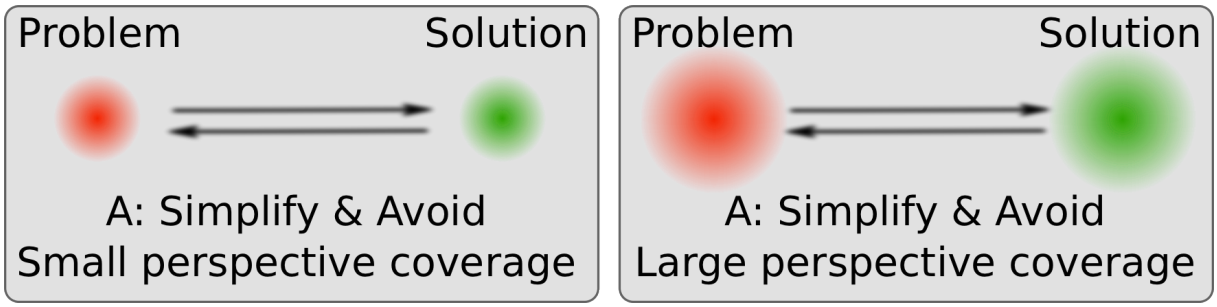


Figure 3: Different perspective coverage within the same conception of the phenomenon. Red circle indicates the problem, green circle indicates the solution.

However, as described in Paper I, coverage is still an important characteristic for describing how well a certain perspective may be suited for contributing to SD, since a larger perspective coverage may "allow the actor to anticipate side effects and thus find more resilient solution approaches", and since it may render the solution process "more democratic and increase[e]

the chances of arriving at a socially acceptable solution" (p.8). Thus, perspective coverage can be understood as a qualifier of perspectives *within* categories as illustrated in figure 2.

5.4 What level of complexity is expressed in perspective shifting and perspective integration processes?

In section 5.2, the papers' descriptions of complexity are discussed and combined. Complexity is identified as important both in the context of identifying perspectives that are useful for approaching complex sustainability problems (Paper I), and in the context of learning to develop more complex understandings of a phenomenon related to such a problem (Paper II).

In Paper I, two operative processes are described that are relevant for understanding what may be needed to develop complex understandings of WSPs: *perspective shifting* and *perspective integration*. Perspective shifting is introduced as "a process in which the actor forms a new relationship towards the object (…) [that] is based on a different conceptual logic and a different way of making sense of the object than the previously formed perspective" (p.10). By changing for example the coverage of perspectives, students may focus on different facets of the object, which in turn may enable them to "become aware of the inherent complexity of the issue" (p.10). Since perspective coverage is understood as a qualifier within categories (section 5.3), perspective shifting processes may be expected within each of the categories described in Paper II (figure 2). Thus, even though these processes are identified as valuable in approaching complex sustainability problems, their presence does not necessarily indicate a complex understanding of the problem itself. However, perspective shifting processes may take different forms depending on which conception is held while performing it. In *simplify and avoid*, perspective shifting, if present at all, is likely to be an unconsciously and unspecifically shifting focus on a number of different vague ideas related to the phenomenon. In *divide and conquer*, the shifting occurs by jumping between isolated aspects of the problem, or by jumping between isolated aspects of the problem and isolated solution approaches. In *isolate and succumb*, the shifting occurs more fluidly by moving in an interconnected web of parts of the problem. The connection between the problem and the solution, however, is broken and no shifting can occur between them. In *integrate and balance*, perspective shifting is a dynamic process of movement in a complex web that is composed of interrelated parts of the problem and solution approaches. Thus, even though perspective shifting processes may be performed while holding any of the different conceptions described in Paper II, different *kinds* of perspective shifting processes may indicate, and possibly mediate, the development of different levels of complexity of understanding WSPs.

Perspective integration is in Paper I described as "the process of combining and relating several perspectives to each other" (p.11). The resulting perspective entails not only a shifting between different foci, but a "simultaneous, combined focus on a number of related aspects [of the object]" (p.11), such as "different domains (society, environment, economy, etc.)" and/or "different scales (local to global)" (Wiek, Withycombe, and Redman (2011), cited in Paper I, p.11). Consequently, perspective integration processes are more challenging than perspective shifting processes and they indicate a rather complex understanding of the

phenomenon. In *divide and conquer*, both problem and solution are viewed as composed of isolated fragments, while in *simplify and avoid*, distinct parts of the problem or the solution are not perceived at all. Thus, no perspective integration occurs while holding these two conceptions. The conception denoted by the category *isolate and succumb* is more complex, at least in relation to the view of the problem (see section 5.2). Perspective integration occurs as the parts of the problem are viewed in a systemic way. The solution, however, is still perceived as consisting of isolated parts, which indicates the absence of integrative processes in relation to the solution. In *integrate and balance* on the other hand, perspective integration spans both parts of the problem and solution approaches, and the phenomenon is viewed as a complex whole of interrelated parts (figure 1). In conclusion, the presence of perspective integration processes may generally indicate the presence of rather complex understandings of WSPs. In addition, similar to what has been described above for different kinds of perspective shifting processes, different ways of performing perspective integration processes may indicate and mediate differences in the levels of complexity of understanding WSPs between the conceptions *isolate and succumb* and *integrate and balance*.

5.5 Are reflection and evaluation critical for complex understandings of WSPs?

In addition to *operative processes*, Paper I also introduces *reflective processes* that deal with the object on a meta-level. These processes include *perspective perception*, which is described as "the process in which an actor first becomes aware of his/her own perspective on the object" and takes "his/her understanding of a sustainability challenge, rather than the sustainability challenge itself, as an object of attention" (p.11). In this process, the focus has shifted from a focus on a sustainability problem, to the students' own perspective on that problem. A second process that is introduced in Paper I is *perspective reflection*, in which the focus on the own perspective is strengthened through active reflection. Finally, p*erspective evaluation* occurs when external normative structures are brought into focus and are related to the own perspective. Perspective evaluation processes are described as "crucial for fruitfully addressing sustainability challenges that require balancing incompatible goals and interests against each other" (p.12). Thus, these reflective processes are highly relevant in discussions about what kinds of perspectives are useful for SD, and they should not be neglected.

However, they cannot be related to the categories presented in Paper II since they refer to the experience of students' *perspectives of a problem* rather than the given *problem* itself, i.e. they may refer to a different phenomenon. Reflection and evaluation were indeed visible in the analysis for Paper II, but they did not emerge as educationally critical aspects in terms of the complexity of students' understandings of WSPs. An empirical study that focuses on, for example, students' ways of understanding the role of a professional engineer might bring out critical aspects related to reflection and evaluation, and possibly add this dimension to an extended discussion on the findings of the research presented in this thesis.

6 Discussion

6.1 Considerations regarding transferability

As discussed in section 0, the two papers that are included in this thesis share some basic philosophical assumptions as well as a focus on engineering students' ways of relating to WSPs. However, while the framework provided in Paper I is conceptual, the results presented in Paper II are based on an empirical analysis. This nature of the results should be considered when attempting transfer to other contexts. In particular, it is not possible to assume that a conceptual framework could be used to elaborate on empirically derived results, since they are based on the researchers' *ideas* about what may be important for a certain context, rather than empirical evidence. Thus, the integrative approach taken in section 5 should be seen as an elaboration on the conceptual model presented in Paper I, rather than on the phenomenographic outcome space presented in Paper II.

The main value of the conceptual framework from Paper I is that it introduces a set of concepts that can be used by EESD researchers and educators as a common language for talking and reflecting about what it can mean to consider a multitude of perspectives in relation to sustainability challenges. Since the concepts are not empirically derived, they are not rigidly defined either and may in principle be used freely in different contexts. However, they are developed in and for the context of EESD. If they are to be used in other contexts, it may be advisable to review, and possibly adapt or elaborate on, the framework. In addition, the concepts are developed in relation to each other, with the ambition to create logical cohesiveness within the framework as discussed in section 0. It is therefore likely that the concepts are more useful in the context of the entire framework, rather than isolated from each other.

The phenomenographic outcome space that is presented in Paper II is more clearly dependent on the specific context of the study than the conceptual framework in Paper I. Mainly, this is due to the fact that the conceptions that are described are conceptions of a specific phenomenon that emerged in the unique context of the described study; it is possible that the exact same conceptions will not be expressed in any other context. However, the results of the study provide insights into the "nature of the different ways of experiencing" the phenomenon, and the "nature of the[se] differences" (Pang, 2003, pp. 146-147). This *nature of ways of experiencing* is likely to allow for a higher level of transferability than the w*ays of experiencing* themselves. For example, it may be possible to use these results in combination with those of other similar studies, and thus to create a broader understanding of the nature of students' conceptions of a certain class of phenomena related to WSPs. It may be particularly interesting to compare the analysis of structural aspects of conceptions of different phenomena in this class. However, as in all phenomenographic studies, the described conceptions are only meaningful in relation to each other. It is therefore not possible to isolate the description of one single conception. Neither is it appropriate to use the categories provided in Paper II to classify or assess individual students.

6.2 Implications for theory

The complexity of students' understanding of WSPs is a central concept in this thesis. Structural features of this complexity have been analyzed (section 5.2), and the relationships between complexity and perspective coverage (section 5.3), and between complexity and operative perspective processes (section 5.4) have been investigated. The findings indicate that complexity of ways of understanding WSPs may be an important concept in EESD that deserves more attention in REESD, but also more generally in EER.

On a more specific level, the research has implications for research about students' understanding of sustainability. As discussed in section 5.3, perspective coverage is not necessarily related to the complexity of the corresponding conception, but should rather be seen as a qualifier of perspectives within each of the categories of conceptions provided in Paper II. This is an interesting observation that may have implications for research done by Segalàs, Ferrer-Balas and Mulder (2008), who use concept maps to quantitatively evaluate the coverage and complexity of engineering students' understanding of the concept sustainability. As indicators for coverage, which they call the "width" of the students' understanding, Segalàs, Ferrer-Balas and Mulder use the number of different concepts that the students name in their concept maps. To estimate the complexity of each understanding, they analyze the connections that the students establish between the concepts in their maps. The focus of Segalàs, Ferrer-Balas and Mulder's study is to evaluate the effectiveness of SD course interventions for helping students to develop broader and more complex understandings of sustainability. They conclude that the analyzed courses have been effective in both respects. Unfortunately, they do not analyze the relationship between coverage and complexity. The results from this thesis suggest that such an analysis would be interesting and potentially valuable for designing effective EESD that provides a balanced development of both perspective coverage and complexity of understanding.

6.3 Implications for practice

An important conclusion from section 5.1 is that students who express the conception *simplify and avoid* may lack a fundamental sense of engagement with the problem. Thus, there may be a relation between unspecific and abstract ways of expression and less complex understandings of the studied phenomenon. Even though the research that underlies this thesis has not dealt with questions of causality, it seems reasonable to assume that students who are trained in using specific and concrete ways of expression related to WSPs may find it easier to develop more complex understandings of these kinds of problems.

Further, from the analysis in section 5.3 can be concluded that, while coverage is an important qualifier of students' understandings of WSPs, it is not sufficient for describing the complexity of these understandings. Consequently, it is also unlikely that EESD aimed at merely introducing as many aspects of WSPs as possible will be successful in helping students to develop the capabilities they need to effectively deal with WSPs. Rather, an integrative approach is needed in which the different aspects of the problem and possible solution approaches are connected and integrated. It is reasonable to assume that this is a challenging learning experience for the students, and that educators therefore must play an important role in scaffolding these integrative approaches.

A suitable educational approach to this scaffolding may be to design activities in which perspective shifting and perspective integration processes are explicitly practiced. However, as indicated in section 5.4, these processes can be performed in various ways, and not all of these ways are conducive for developing a complex understanding of the situation at hand. Educators should particularly try to scaffold perspective shifting processes between problem parts and solution approaches (for conception *divide and conquer*), or within an integrated web of problem parts and solution approaches (for conception *integrate and balance*). Similarly, practicing perspective shifting and perspective integration processes only related to the problem, without taking the connections between problem parts and solution approaches into consideration, should be avoided since students might get "stuck" in the *isolate and succumb* conception. As argued in Paper II, this would be a rather unproductive educational outcome in terms of equipping students with the capabilities they need to handle WSPs.

6.4 Outlook on future studies

In theoretical terms, the results presented in this thesis offer an exploration of the nature and function of perspectives and a description of different ways of understanding WSPs in EESD. They do not yet provide a practical guide to working with WSPs in EESD. Because EESD is experienced as challenging for both students and educators, it would be interesting and valuable to explore the relationship between these theoretical ideas and EESD practices in more depth. How could the theoretical results be further elaborated on to be more valuable for EESD practitioners? How could the existing gap between research and practice be bridged more effectively? Answers to these questions could provide insights into EESD practitioners' needs of competence development, and contribute to a better understanding of the relationship between educational theory and practice on a more general level.

One aspect of this elaboration of the results could be practical implementation of the concepts in a concrete educational situation. For example, different implementation designs could be evaluated and compared in terms of their effectiveness for achieving EESD learning outcomes. Such an analysis could provide valuable and more directly applicable insights into what may constitute high quality EESD, how educational ideas are put into practice in EESD, and what kinds of challenges EESD-practitioners face as they attempt to do so.

Further interesting aims for theoretical investigation based on the results presented in this thesis might be a better understanding of the nature of different ways of experiencing phenomena related to WSPs (see section 6.1), of complexity in EESD (see section 6.2), or of the relationship between reflective processes and conceptions of WSPs (see section 5.5). It may also be interesting to study the relationship between students' conceptions of WSPs and emotional aspects, particularly related to conception *isolate and succumb*. Such investigations may add considerably to the overall aim of this thesis, which is to find ways of supporting students of engineering in developing the capabilities that they need to actively participate in discussions about SD and to constructively deal with WSPs.

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LIST OF PUBLICATIONS

This thesis is based on the work contained in the following papers.

Paper I:

Lönngren, J., Svanström, M., Ingerman, & Å., Holmgren, J. A Conceptual Model of Perspectives for Sustainable Development – Examples from the Context of Engineering Education. *Submitted to European Journal of Engineering Education.*

Paper II:

Lönngren, J., Ingerman, Å., & Svanström, M. Avoid, Conquer, Succumb, or Balance: Engineering Students' Conceptions of and Approaches to a Wicked Sustainability Problem. *In manuscript.*