

Centrum för klimat och säkerhet
Rapport 2019:3

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Centrum för klimat och säkerhet | 2019:3

ISBN: 978-91-7867-031-4 (tryck) | 978-91-7867-036-9 (pdf)

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Karlstads universitet
Centrum för klimat och säkerhet
651 88 Karlstad
054-700 10 00

Tryck: Universitetstryckeriet, Karlstad 2019

Authors

1. **Malin Mobjörk**

Senior Researcher, Stockholm International Peace Research Institute, SIPRI

2. **Camilla Berglund**

PhD, School of Humanities, Education and Social Sciences, Örebro University

3. **Mikael Granberg**^{1,2,3}

¹ Director, the Centre for Climate and Safety, Karlstad University

² Professor of Political Science, Department of Political, Historical, Religious and Cultural Studies, Karlstad University

³ Research fellow, Centre of Natural Hazards and Disaster Science, Uppsala University, Karlstad University & Swedish Defence University.

4. **Magnus Johansson**^{1,2}

¹ PhD in Physical Geography, Centre for Climate and Safety, Karlstad University

² Research Fellow, Centre of Natural Hazards and Disaster Science, Uppsala University, Karlstad University & Swedish Defence University.

5. **Margareta Dahlström**^{1,2}

¹ Director of Centre for Regional Studies, Karlstad University

² Professor of Human Geography, Department of Geography, Media and Communication, Karlstad University

6. **Jon Moen**

Professor, Department of Ecology and Environmental Science, Umeå University

7. **Lars Nyberg**^{1,2}

¹ Associate Professor, Centre for Climate and Safety, Karlstad University

² Research Fellow, Centre of Natural Hazards and Disaster Science, Uppsala University, Karlstad University & Swedish Defence University.

8. **Mariele Evers**

Professor of Geography, Head of working group hydro-ecology and water resources management, Geography department, University of Bonn, Germany

Acknowledgements

We would like to extend our heartfelt thanks to the PhD candidates who have been interviewed. Similarly, we also want to thank those PhD candidates who contributed to the workshop held at Karlstad University that informed the interview guide used. We are also grateful for valuable comments received at two seminars at Karlstad University on earlier drafts of this report. Last, but not least, we are grateful for financial support from the Swedish Civil Contingencies Agency (MSB) and the Swedish government through its strategic research area funding for the Centre for Natural Hazards and Disaster Science (CNDS).

Highlights

- Doctoral education is a vital phase of shaping the future cadre of researchers.
- The paper explores PhD candidates' experiences from being engaged in cross-disciplinary settings focusing on sustainable development.
- In research milieus that have held meta-discussion about cross-disciplinarity, PhD candidates are more comfortable to situate themselves.
- Cross-disciplinary milieus should discuss cross-disciplinarity throughout the doctoral education beginning in the recruitment phase.

Abstract

The doctoral education is a formative phase in a scientist's intellectual development. Cross-disciplinarity shapes much research today and many PhD candidates are engaged in this research. Despite a large body of research about cross-disciplinarity, less attention has focused on how cross-disciplinarity shapes doctoral education. This report explores this space and builds on the experiences of PhD candidates engaged in research characterised by cross-disciplinarity on and for sustainable development. Drawing on pedagogical research on socialisation, we analyse how these research milieus have organised their doctoral education and the PhD candidates' experiences of pursuing their education in these milieus. The aim is to contribute with insights on how research milieus can facilitate future cross-disciplinary doctoral education.

The analysis finds that PhD candidates belonging to milieus providing courses and seminars about cross-disciplinarity are more confident situating their own research. The engagement of senior staff and supervisors in these activities is key in developing a conceptual apparatus and building the capacity to interact with different fields of science and with practitioners to meet diverse future challenges. The findings show the importance of research milieus providing space for communicating about cross-disciplinarity throughout the doctoral education and that this process already starts during recruitment process.

Keywords

Cross-disciplinary; Multidisciplinary; Interdisciplinary; Transdisciplinary; Doctoral education; Sustainable development

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1 Introduction

Challenge-driven research shaped the European Union's research programme Horizon 2020 as well as the global research initiative Future Earth. This involves that research areas such as sustainable development and global health are pursued in cross-disciplinary research settings (Hirsch Hadorn et al. 2006; Brandt et al. 2013; Lang et al. 2012; Thompson Klein 1996; 2004; 2014). In this report, cross-disciplinarity is used as an umbrella concept that includes multi-, inter- and transdisciplinary research (Mobjörk 2010). Cross-disciplinary research emerges in different contexts – in research programmes, in research centres and in new academic divisions – cutting across the conventional academic boundaries between disciplines. Cross-disciplinary research is often connected to the idea of change, i.e. that knowledge processes should contribute to more sustainable societies through economic, technological and institutional transformations (Schneider & Rist 2013; Popa et al. 2014). As such, much of this research is future oriented.

Cross-disciplinary research aims at addressing complexity, acquiring contextualised knowledge and facilitating transformation. Collaboration between different academic disciplines and between researchers and other societal actors are key elements. This poses methodological challenges and requires skills for engaging, collaborating and communicating with a diverse set of actors (Kemp & Nurius 2015). Accordingly, this shift in research involves new roles for researchers (Wittmayer & Schöpke 2014) and Hirsch Hadorn et al (2006:123) even argue that researchers enter into '...unfamiliar grounds for scientific knowledge production'. As a substantial part of research is conducted by PhD candidates (e.g. in Sweden, a third of all research is conducted by PhD candidates¹), we argue that in-depth studies of the experiences of PhD candidates is vital. The doctoral education phase is formative in the intellectual development of a researcher and

¹ This figure is provided by Statistics Sweden and covers 2015, see: <http://www.scb.se/hitta-statistik/statistik-efter-amne/utbildning-och-forskning/forskning/forskning-och-utveckling-inom-universitets--och-hogskolesektorn/pong/statistiknyhet/namnlos/>

subsequently shapes future research (Mitrany & Stokols 2005; Graybill et al. 2006; Gaya & Brydon-Miller 2017).

The doctoral education is formed by organisational settings, such as individual projects or graduate schools, disciplinary departments or cross-disciplinary research centres, as well as by funding conditions. Accordingly, it is crucial to take into account that doctoral education is offered in diverse research milieus shaped by various forms of cross-disciplinary thinking. This report explores this space through the experiences of PhD candidates from four different research milieus characterised by various approaches to cross-disciplinary research within the field of sustainable development. More specifically, we explore how these four cross-disciplinary research milieus organise their doctoral education and what experiences PhD candidates in these milieus have had. The overarching goal is to gain knowledge about how cross-disciplinary research milieus can develop doctoral education, which is pivotal in fostering the next generation of researchers. The report is based on a free text survey to the research directors of the four research milieus and on semi-structured interviews with 14 PhD candidates enrolled in these milieus.

Next, we give an overview of contemporary knowledge on cross-disciplinary research and of research on the socialisation of PhD candidates in cross-disciplinary research settings. The analytical framework guiding the analysis is informed by these two strands of research. Section three presents the empirical data. The fourth section involves the analysis, which is structured along three themes: 1) The initiation and introductory phase; 2) Knowledge acquisition, arenas and networks; and 3) Supervision and the doctoral education milieu. In the final section, we summarise the findings and formulate a set of recommendations aiming at improving the PhD education offered in cross-disciplinary research milieus.

2 Theoretical perspectives

2.1 Cross-disciplinary research

A joint feature in cross-disciplinary research is the expectation to transcend disciplinary boundaries in dealing with complex issues (Thompson Klein 1996; Schmidt 2008; Scholz & Steiner 2015). Two major motives can be outlined behind the call of cross-disciplinarity; a science-driven approach seeking a more holistic understanding of society and nature, or a problem-focused approach shaped by societal actors' demands for research to address, manage or even solve pressing challenges in society (Pohl 2008; Mobjörk 2010). Contextualised knowledge plays a pivotal role in both these strands, which also include a critique of modern science, especially its tendency towards specialisation and thus detachment from lived experiences (Hirsch Hadorn et al. 2006; Schmidt 2008). The problem-focused approach, sometimes labelled Mode 2 knowledge production (Gibbons et al. 1994), came to the fore during the 1990s and has, for instance, shaped Horizon 2020, the European Union's research programme, and the global research initiative Future Earth (EU COM 2011; Future Earth 2013). Core features of cross-disciplinarity are, besides its problem-focused approach, the call for collaboration between researchers from different disciplinary backgrounds and – to various degrees – with actors from outside academia (Jahn et al. 2012). Cross-disciplinary research is often linked to innovation and transformation (Kauffman & Arico 2014; Lang et al. 2012) and is, as such, value-laden (Barth & Michelsen 2013). Because it often involves an idea of fostering change, it has been compared to action-oriented research (Popa et al. 2014). However, this norm can be more or less salient, since the approach also involves grasping complexity. Altogether, cross-disciplinary research involves various approaches for acquiring knowledge, different forms of collaboration, and exceeds conventional concepts of basic and applied research (Jerneck et al. 2011).

Much research on cross-disciplinarity has focused on identifying and distinguishing specific cross-disciplinary approaches (Robinson 2008; Pohl 2008; Huutoniemi et al. 2010; Balsiger 2015). Three major types of cross-disciplinarity has been outlined: multi-, inter- and transdisciplinarity (Mobjörk 2010). *Multidisciplinarity* is commonly understood as a collaboration between researchers from different disciplines analysing a specific problem

from their respective angles. *Interdisciplinarity* involves a closer collaboration aiming to develop a joint understanding of the problem and merging the different researchers' approaches to investigate this. *Transdisciplinarity* expands this joint understanding to involve actors from outside academia. Research on cross-disciplinarity mostly addresses inter- and transdisciplinarity, since these two types more explicitly transcend disciplinary boundaries. Simultaneously, these approaches to research span across descriptive-analytical approaches and problem-solving or process-oriented approaches (Wiek et al. 2012; Wittmayer & Schöpke 2014), and collaboration shifts through the research phase, depending on the knowledge required (Pohl & Hirsch Hadorn 2008). Accordingly, research including any form of cross-disciplinarity is always heterogeneous.

Despite the heterogeneity of cross-disciplinary research, it is formed by high expectations regarding its potential, both in terms of knowledge acquisition and in terms of its contribution to the handling of pressing societal challenges (Polk 2014). Simultaneously, cross-disciplinary research is challenging academia, questioning its organisational and institutional structure (Boden et al. 2011) and requires structural change to foster new skills and competences among students and researchers (Lang et al. 2012; Muhar et al. 2013). Research on cross-disciplinarity has addressed methodological challenges involved, which includes methods for participation and collaboration (Pohl & Hirsch Hadorn 2008; Bammer 2008). Previous research has also addressed the challenges cross-disciplinarity poses to evaluation and quality criteria (Carew & Wickson 2010; Jahn & Keil 2015), as well as its impact on academic careers (Tress et al. 2009; Bridle et al. 2013).

In addition, there are also a substantial number of articles based on researchers' own experiences of conducting cross-disciplinary research (see e.g. Binder et al. 2015; Beland & Westholm 2014; Guimaraes et al. 2014; Mattor et al. 2014). Most of this research builds on senior researchers' experiences, but a number of articles also explore the experiences and approaches taken by PhD candidates themselves (Enengel et al 2011; Haider et al 2017). These self-reflective analyses contribute to sharing experiences. However, we believe these analyses might benefit from taking into account the pedagogical research on socialisation processes in cross-disciplinary settings as well as emerging from PhD candidates experience from different research milieus.

2.2 The socialisation of cross-disciplinary researchers

Doctoral education is a formative part of a scientist's intellectual, social and academic development (Mitrany & Stokols 2005; Graybill et al. 2006; Gardner et al. 2014; Felt et al. 2013). This process, known as socialisation, involves the process through which the individual adopts the values, skills, attitudes, norms and knowledge needed for becoming a member of a given organisation (Gardner et al. 2014). As Boden et al. (2011) discuss, many challenges PhD candidates face during the socialisation process are generic, but, they argue, some challenges are more prominent in cross-disciplinary programmes than in disciplinary programmes. In order to outline the way in which these challenges arise, it is important to reflect on what a discipline is as well as the primary features and stages of the socialisation process.

All discussions of cross-disciplinarity emerge from an idea about what a discipline is (Thompson Klein 1996; Salter & Hearn 1996). Thompson Klein (1996) has suggested that a discipline is delineated by differences in theories, methods and conceptual frameworks, as well as by its institutional setting, which includes organisational, social and cultural dimensions. Gardner et al. (2014) adopt a similar view, emphasising that a discipline provides the history, a set of norms, practices and values, and a sense of identity, together with a set of epistemological tools and mind-sets. A discipline can, accordingly, be understood both as a branch of knowledge and as a means of social control (Salter & Hearn 1996). Thus, socialisation is the process that leads to inclusion in a discipline. Importantly, this process is not static or linear, instead it is dynamic and involves changes through mutual exchange between established and aspiring members (Gardner et al. 2014). It also involves changes in academia due to external research policy decisions and funding structures (Thompson Klein 1996).

Disciplines are heterogenous and change over time, but despite this, researchers share the view that socialisation processes in cross-disciplinary research education differs from those in an established discipline (Gardner et al. 2014; Boden et al. 2011; Bridle et al. 2013; Felt et al. 2013). Boden et al. (2011:4) specifically highlight that the "...organization structure lies at the heart of many of the challenges to interdisciplinary research and graduate training" and cross-disciplinary researchers need to work across organisations' often

hierarchical structures. Vanstone et al. (2013) point towards institutional constraints as a major challenge for PhD candidates working in cross-disciplinary settings, which illustrates that cross-disciplinarity calls for cultural and institutional changes within academia (Tress et al. 2009). As a consequence, the norm and reward systems in academia tend to work against cross-disciplinarity (Bridle et al. 2013; Gardner et al. 2014; Felt et al. 2013).

Gardner et al. (2014) outline three core demands in the socialisation process of PhD candidates: *knowledge acquisition*, involving both cognitive and tacit skills for the chosen profession; *investment*, referring to the development of identity and commitment; and *involvement*, referring to participation and the development of a professional role. The department and supervisors play a significant role in these processes. This involves how the skills and purposes of prospective students are taken into account during the recruitment process, which courses are offered, and how they are offered, and how knowledge on cross-disciplinarity is dealt with throughout doctoral education. In addition, the supervisors' own experiences of cross-disciplinarity play an important role, as well as how engagement both within and outside academia is facilitated (Gardner et al. 2014). Together these factors influence the socialisation process of PhD candidates and, accordingly, their development of competences, skills and networks for conducting cross-disciplinary research.

In scholarly research focusing on the socialisation processes of cross-disciplinary researchers, we have identified some general patterns. Studies have observed that the interplay between the PhD candidates' motivation and the organisational setting is crucial for understanding the challenges that PhD candidates face in cross-disciplinary doctoral education (Boden et al. 2011; Muhar et al. 2013; Gardner et al. 2014). A study by Felt et al. (2013) of early-career researchers pursuing transdisciplinary research point towards the need for researchers to adopt strategies for positioning themselves in multiple forums. Moreover, they identify that researchers planning an academic career consider transdisciplinary research detrimental to their career, because it is perceived to take longer and does not fit into the traditional academic quality assurance and reward system. To reduce these problems, Felt et al. (2013) stress the importance of academic organisations and funding agencies' revising their quality assurance structures and financing criteria to facilitate cross-disciplinary research and support to emerging researchers.

Accordingly, cross-disciplinary research not only challenges the established academic system (Boden et al. 2011; Felt et al. 2013), it also poses specific challenges for individual researchers (Lang et al. 2012, Muhar et al. 2013; Augsberg 2014; Kemp & Nurius 2015). These challenges include: building networks in the realm of unfamiliarity; contextualising complex and multilevel problems; engaging and collaborating with researchers from different disciplines and with different stakeholders; using theories from multiple disciplines in the development of integrative multilevel conceptual frameworks flexibly; publishing with colleagues from different disciplines; and disseminating research results within and beyond academic contexts (Kemp & Nurius 2015; Augsberg 2014).

2.3 Analytical framework

This report's theoretical foundation rests on contemporary research and theories on cross-disciplinarity on the one hand, and pedagogical research on the socialisation of PhD candidates, particularly in the context of cross-disciplinarity, on the other. We bring these two strands of research together to create an analytical framework for analysing doctoral education in four cross-disciplinary settings focusing on sustainable development. Research on cross-disciplinarity provide the context that helps us to structure cross-disciplinary research and uncover the demands faced by researchers paying attention to the diverse types of cross-disciplinarity (Mobjörk 2010; Barth & Michelsen 2013). We connect this to research on socialisation that centres on individual researchers' development into members of a research community (Gardner et al. 2014; Felt et al. 2013; Boden et al. 2011). Three thematic areas are identified in the research literature and used to structure our analysis.

The first theme – *the initiation and introductory phase* – focuses on preparedness, motivations and expectations (cf. Boden et al. 2011; Muhar et al. 2013; Felt et al. 2013; Gardner et al. 2014). Our focus is on if, and how, PhD candidates and research milieus already in the early phases address issues of cross-disciplinarity and if there are any reflections on what this might entail for organising doctoral education and for individual PhD candidates. This dynamic is captured through the responses from research directors to our survey, describing the starting phases of each doctoral education milieu and through the interviewed PhD candidates' expectations entering doctoral education. A key aspect is

whether and how cross-disciplinarity is introduced and communicated in the introductory phases of the doctoral programme and on how cross-disciplinarity is understood among the PhD candidates.

The second theme – *knowledge acquisition, arenas and networks* – focuses on how knowledge is provided by the doctoral education milieu and acquired by the PhD candidates in terms of courses and seminars and if the PhD candidates are introduced to conceptual and methodological discussions of cross-disciplinarity. It also addresses the networks connected to the milieu and the PhD candidates' access to these networks as well as their engagement in network-building activities within and across academia (Tress et al. 2009; Boden et al. 2011; Vanstone et al. 2013; Felt et al. 2013). This theme further focuses on the cognitive skills acquired through formal training in methods and theory (Gardner et al. 2014).

The third theme – *supervision and the research education milieu* – focuses on the appointment of supervisors, supervisors' experiences of cross-disciplinarity, and the character of the research milieu in terms of cross-disciplinarity (cf. Lang et al. 2012, Muhar et al. 2013; Augsberg 2014; Kemp and Nurius 2015). Cross-disciplinary milieus need to be open to interaction and this includes the supervisors' experiences and attitudes towards cross-disciplinarity. The doctoral education milieu and the supervision of PhD candidates influence the socialisation process of these PhD candidates and the development of competences and skills in conducting cross-disciplinary research.

3 Empirical data

The empirical data consists of a free text survey to the research directors of four cross-disciplinary research milieus and semi-structured interviews with PhD candidates enrolled in these milieus. The four research milieus (Table 1) reflect the heterogeneity of both cross-disciplinarity and research on and for sustainable development. The survey focused on the institutional background of the research milieus and how they have organised doctoral education, specifically in terms of recruiting PhD candidates, appointing supervisors, offering courses that include cross-disciplinarity, and stimulating PhD candidates' ability to build networks. This survey serves as a background for understanding the context in which the PhD candidates have been enrolled.

The primary empirical data for the analysis is the semi-structured interviews with PhD candidates. 14 interviews were conducted over telephone or Skype by the same interviewer. The interviews were recorded and transcribed. Quotes from the interviews were translated into English when needed, and the interviews are labelled as MITPHD_ *number* and with reference to the line in the transcript referred to. Identifying information in the quotes have been removed. Before the interviews were conducted a workshop was organised with PhD candidates from two of the four research milieus. This workshop contributed to the design of the interview guide, which covered four areas: PhD candidates' background and the initial phases of their PhD education; the institutional set-up of doctoral education including courses and seminars; the appointment of supervisors and their cross-disciplinary role for the PhD candidate; and, finally, network building within and beyond academia.

The empirical data used in this analysis are not comprehensive enough for a thorough comparative analysis between the research milieus; instead, our approach is more explorative and aims to investigate the organisation of doctoral education at these milieus and the experiences of the PhD candidates. This approach, however, enables us to identify similarities and differences across the four research milieus. We identify critical factors in the institutional organisation of cross-disciplinary doctoral level education. The PhD candidates also reflected on what could have been done differently to benefit their work. These reflections are also important for our conclusions.

Table 1. The four research milieus

	Karlstad University – The Centre for Regional Studies	Karlstad University – Risk and Environmental Studies	Umeå University – a research project (2008- 2015)	Bonn University – Eco hydrology and water resource management
Main cross-disciplinary approach	Multi-disciplinary	Interdisciplinary	Interdisciplinary	Inter- and transdisciplinary
Faculty	Arts and Social Sciences	Health, Science and Technology	Science and Technology	Mathematical and Natural Sciences
No of senior researchers	17	9	6	2
Disciplines in which the senior researchers hold their PhDs	Historical archaeology History Human geography Political science Social work Sociology	Environmental & energy systems Historical archaeology History Hydrology Physical geography Political science Public health sciences Risk & environmental studies Social medicine	Ecology Forest history History History of medicine Political science	Geography/Engineering Geo-ecology
Cross-disciplinary publications in senior researchers' bibliographies?	Yes (14), No (3)	Yes (9)	Yes (6)	Yes (2)

	Karlstad University – The Centre for Regional Studies	Karlstad University – Risk and Environmental Studies	Umeå University – a research project (2008- 2015)	Bonn University – Eco hydrology and water resource management
Current positions - Disciplines in which the senior researchers are employed in during 2016	Environmental science History Human geography Risk- & environmental studies Political science Social work Sociology Tourism studies	Environmental science Risk Management Risk & environmental studies	Forest history History Human geography Political science Sustainability science	Geography Hydrology
No of PhD students on 1 January 2016	12	10	4	8
Subject in which PhDs are awarded	History Human geography Political science Risk & environmental studies Sociology Social work	Risk & environmental studies	Ecology History Political science	Geography

4 Analysis

4.1 *The four research milieus*

4.1.1 The initiation and introductory phase

The research milieus all have different origins and this illustrates the diversity of cross-disciplinary research. Two of them, *The Centre for Regional Studies (CRS)* and *Risk and Environmental Studies (RES)* were established with the explicit aim to obtain sufficiently large research milieus for offering doctoral education. This can be contrasted by *The eco hydrology and water resource management* milieu (EHWRM) which is part of a large department, but characterised by a small number of senior researchers and a comparatively large number of PhD candidates. The fourth milieu is a research project, *Adaptations of natural resource-based communities to climatic and societal changes - Sami reindeer herding in the past, present and future*, hosted by Umeå University and funded by The Swedish Research Council for Sustainable Development.

The research milieus align themselves to different types of cross-disciplinarity and have acted differently in the recruitment of PhD candidates. The CRS describes itself primarily as being multidisciplinary, which mirrors its origin i.e. to pool enough competences from several small research milieus to achieve a critical mass for providing doctoral education. Both the supervisors and PhD candidates remains in their disciplines. No discussions have been conducted with applicants to the PhD positions about multidisciplinary during the recruitment process. Similarly, neither RES nor EHWRM, who align themselves to interdisciplinary and the latter to some degree also to transdisciplinary research, have discussed the research milieus' cross-disciplinary character during the recruitment process. One difference is though that RES is an interdisciplinary subject, meaning that senior researchers have different disciplinary backgrounds and that they, together with the PhD candidates, now belong to a recently established discipline, Risk and Environmental Studies.

The only research milieu that explicitly has discussed the milieus' cross-disciplinary character is the project hosted by Umeå University. Four PhD candidates was recruited to

the research project that formed the foundation of this research milieu. During the recruitment process, it was clearly described that the PhD candidates were going to work in an interdisciplinary context, and that they were expected to collaborate and participate in interdisciplinary activities.

4.1.2 Knowledge acquisition, arenas and networks

All four research milieus have offered various activities to support the PhD candidates' socialisation processes. There are large differences across the milieus regarding to what extent, and how, these activities also have included explicit conceptual and methodological aspects of cross-disciplinarity. At CRS no courses or seminars have explicitly addressed cross-disciplinarity. Some seminars and study visits to similar research milieus have been organised. At RES, courses and seminars have been influenced by interdisciplinarity. The interdisciplinary approach characterising these activities has primarily been practice-oriented, i.e. influencing the network with diverse academic departments and societal actors. No courses or seminars have explicitly addressed conceptual or methodological reflections on cross-disciplinarity. This is also the case at EHWRM at Bonn University. At EHWRM, PhD candidates don't have any compulsory courses, which distinguish the German PhD education system from the Swedish system. At EHWRM, the cross-disciplinary activities have mostly been integrated through interaction with actors outside academia and joint conferences highlighting its transdisciplinary profile. The research milieu at Umeå University, is the only one that has offered courses that explicitly address cross-disciplinarity. Besides providing two courses about cross-disciplinary concepts and tools, the research milieu at Umeå University have organised seminars and project conferences addressing inter- and transdisciplinary approaches to research. Interestingly, these seminars and conferences have included both senior researchers and PhD candidates. They have also jointly attended other external inter- and transdisciplinary research conferences.

4.1.3 Supervising and the research milieu

The four research milieus have adopted diverse approaches when appointing supervisors, and there are differences in the engagement of supervisors' in the research milieus cross-disciplinary profile as well. The supervisors of CRS and EHWRM have a disciplinary

background in the discipline that the PhD candidates will receive their doctoral degree in. At CRS, most PhD candidates also have a co-supervisor, but both the main and co-supervisor come from the same disciplinary background. The appointment process of supervisor has not paid attention to whether the supervisor have experiences of cross-disciplinarity and some supervisors have not been actively involved in the research milieu. This can be compared with RES and the research milieu at Umeå University. In both these milieus PhD candidates have at least two supervisors coming from different disciplinary backgrounds. This has been a deliberative choice from the directors of these research milieus with the aim to strengthen the interdisciplinary approach. The PhD candidates involved in the research milieu at Umeå University receives their PhD degree within their discipline of origin (political science, history or ecology). This can be contrasted with EHRWM in which the examination is in the subject area of Natural Sciences, irrespective of the background of the PhD candidate. At RES, instead, the examination is held in a newly established discipline – Risk and Environmental Studies – which illustrates that what is conceived as a discipline also changes over time.

4.2 The PhD candidates

4.2.1 The initiation and introductory phase

The PhD candidates' reasons for starting a doctoral education vary, but curiosity originating from experiences from either work outside academia or from previous contacts with research or their experiences of graduate studies, is a key driver. Most frequently, they describe their enrolment as a result of chance, and only a few PhD candidates describe their motives in terms of career. In most cases, the topic of their dissertations has developed from an earlier graduate paper or from other experiences within or outside academia. Furthermore, the intersection between societal and environmental challenges attracted several of the PhD candidates, and an important objective is to bridge academic research and practice. This is highlighted by one PhD candidate who describes experiencing an implementation gap when abstract models meet real world situations:

And then I was thinking whether this actually solves the problem, and whenever you see a reality and try to use it and apply it, I saw there was a lot more to do, so I thought it would be a good idea to work on that concept. (MITPHD2, 335-341).

Accordingly, one important expectation behind this PhD candidate's research is to assess and improve research tools and contribute to social benefits. Among the PhD candidates the desirable outcomes mentioned include theoretical, methodological and communicational tools for handling issues of complexity and contributing to social transformation. Some PhD candidates describe research tools as valuable and necessary to achieve social benefits, while others regard them as important for a future career within or outside academia.

Reasons for pursuing a doctoral education can also be related to how the PhD candidates initially thought about, and reflected on, cross-disciplinarity. Some PhD candidates express very deliberate reasons for pursuing a doctoral education in a cross-disciplinary environment:

I never asked myself that question, because I worked here, and if I were to get a doctorate it had to be on a cross-disciplinary theme. (MITPHD10, 3141-3142).

A common factor among the PhD candidates stressing cross-disciplinarity are their previous experiences of cross-disciplinarity, and also that they – as in the quote above – already were working in such settings. The interviews illustrate that the PhD candidates who had previous experience of cross-disciplinarity deliberately considered this approach interesting and attractive. In the research project at Umeå University, the supervisors explicitly addressed the fact that the students were going to be enrolled in a cross-disciplinary environment during the recruitment process. This was not the case at CRS. The PhD candidates at Umeå University seem to be more satisfied and comfortable with the cross-disciplinary approach shaping their doctoral education. This is related to how the research milieus have organised doctoral education and the PhD candidates' experience of this.

4.2.2 Knowledge acquisition, arenas and networks

Doctoral courses and seminars have the potential of creating arenas for PhD candidates to meet, discuss and exchange ideas. In the German case, doctoral education does not include courses, whereas in Sweden PhD candidates take mandatory and non-mandatory courses as part of their doctoral education. The three Swedish research milieus offer courses that,

to various degrees, address cross-disciplinary concepts and approaches. Our interviews demonstrate that courses and seminars are perceived as important arenas for knowledge exchange and the courses are described as having a considerable influence on the development of the thesis. PhD candidates enrolled in a research milieu where they have been introduced to cross-disciplinary thinking and concepts are more comfortable discussing and relating their work to different cross-disciplinary approaches. The candidates from milieus where that has not been the case describe a lack of identity and lack of a joint conceptual apparatus:

... we may speak the same language within this group, but I feel I lack something, and this I think we all feel a lack of. It is not like in political science, where you have a common ground, that this word means this, and this is a theoretical basis that we are relying on, we have a common conceptual apparatus. (MITPHD4, 1394-1399).

The same PhD candidate presents a suggestion for counteracting this perceived downside:

We need a kind of forum where you actually discuss ... what cross-disciplinarity is, what sort of cross-disciplinarity we are dealing with, how we define it and how we practise it (MITPHD4, 1399-1404).

This illustrates that the research milieus play an important role in providing an arena for addressing cross-disciplinary issues, laying the foundation for a common understanding of cross-disciplinarity in its various forms.

Another pattern is that PhD candidates who have been enrolled in research milieus where the supervisors and the senior staff engages in cross disciplinary research also self-organise activities to address cross-disciplinarity. Informal seminars are the most common expression of this, but other activities organised by the PhD candidates have included the establishment of a network and production of edited volumes. These activities have also to various degrees involved the senior researchers. These more or less self-organised activities provide an arena for the PhD candidates in which they can interact, develop cross-disciplinary approaches and shape the milieu, but it is also considered challenging since it requires time and confidence:

... you have in a way been part of shaping the doctoral education when you have been a student yourself, and I cannot say if it has been for better or for worse. (MITPHD13, 4135-4138).

Connected to this is the struggle to adapt to and handle perspectives, methods and theories from different research fields and academic disciplines. Being enrolled in a cross-disciplinary milieu involves a plethora of research perspectives. Several PhD candidates also express a feeling of being generalists rather than specialists:

... Maybe I am not a specialist in anything ... and it can sometimes feel like a draw-back or weakness. (MITPHD3, 860-863).

... there's nowhere you feel you have this deep knowledge which make you feel stable; you are always swaying a bit. This can feel troublesome ... but also very exciting. (MITPHD13).

Another dimension of bridge building in cross-disciplinary settings is collaboration both within and outside academia. Accordingly, the networks surrounding the research educations milieus are of great importance for the socialisation processes.

4.2.3 Supervision and the research milieu

The interviews demonstrate the important role of supervisors and the research milieu have for the PhD candidates' confidence in terms of relating to cross-disciplinarity. There is also an overall positive opinion about belonging to a supportive cross-disciplinary milieu. On the whole, the PhD candidates consider the milieu critical in getting involved in and establishing networks both within and outside academia, and this occurs through conferences, courses and projects. In addition, the PhD candidates also describe the milieu as an important forum for testing ideas and receiving feedback on texts. In that sense, the milieu is a valued complement to the supervisors. However, a lack of communication between supervisors, and between the discipline in which the PhD candidate will defend their thesis and the cross-disciplinary milieu is also recognised as troublesome. The supervisors are deemed to play an important role in guiding PhD candidates in navigating the multifaceted cross-disciplinary environment, as well as in managing feedback stemming from different research traditions. As previously outlined, the different usage of concepts

sometimes presents a communication challenge in cross-disciplinary milieus and in supervision situations. The absence of a common language could also cause a perceived lack of support especially when supervisors are not involved in the milieu or do not have experience of cross-disciplinary research themselves:

One of my supervisors was part of this cross-disciplinary project, and so was the one who got me to apply for the position. That supervisor was very decisive or had very strong opinions about how the thesis should be done, that it should be cross-disciplinary and also a compilation thesis. [...] The other supervisor was not involved in the project but held a position in the discipline where I later defended my thesis ... and moreover not as positive about the cross-disciplinary approach. (MITPHD7, 2495-2503).

This addresses the importance of strategic thinking when appointing supervisors. As expressed by one PhD candidate, leaving the paved road to enter more unfamiliar territories adds a layer of vulnerability and one has to be able to defend one's chosen path, and the research milieu and supervisors play an important role in doing this:

Especially the first years, when you are about to find an identity, in a new university, a new institution, a discipline, as a PhD candidate, your role is changing. If you are in any way unconventional, you will be questioned, and it can be tough. And I think this was a hindrance for me the first years, and I was very worried about what others would think. It was as if I needed to use both a belt and suspenders at the institution, to somehow legitimise why this is interesting (MITPHD12, 3782-3788).

5 Conclusions

This report has explored the organisation of doctoral education in four cross-disciplinary research milieus and the experiences of 14 PhD candidates enrolled in these milieus. The rationale behind this approach is to provide insights into how doctoral education in cross-disciplinary milieus can take into account the experiences from PhD candidates and develop their capacity to meet the needs of PhD candidates. Before turning to the key conclusions and recommendations, we would like to emphasise that PhD candidates – irrespective of whether the students are enrolled in a discipline or a cross-disciplinary research milieu – are

dependent of the supervisors' ability to provide support to create stability and a sense of belonging. However, our study supports the findings of Boden et al. (2011) stating that the socialisation process in cross-disciplinarity differs and adds an additional layer of challenges for the PhD candidates. To counteract these challenges, PhD candidates' experiences are crucial to take into account when research milieus organise their cross-disciplinary doctoral education. As already stated above, the doctoral education is key for shaping the next generation of researchers and strategic thinking is needed to facilitate this process creating positive and durable outcomes.

Below, we summarise our findings based in the three themes in the analytical framework and present suggestions on how research milieus can develop their way of organising cross-disciplinary doctoral education.

The initiation and introductory phase: It is evident from the interviews that cross-disciplinary issues are not always extensively discussed at the outset, which suggests that some PhD candidates have been enrolled in a research milieu without having a clear understanding of the character of the milieu or the potential impact of this path for their future academic career. The PhD candidates themselves are responsible for acquiring relevant knowledge about the department or research centre they apply to, but the recruitment committees also have a responsibility to discuss this topic. This is also in the research milieus' own interest. The interviews clearly illustrate that the processes of introduction and integration into the research milieu work better if the cross-disciplinary approach has been explicitly formulated and communicated from the beginning. Accordingly, explicit meta-communication about cross-disciplinarity is needed and this should continue throughout the doctoral education. In traditional disciplines, PhD candidates are expected to describe and justify their research by explaining why and how their contribution is within the focus of the discipline. This type of exercise should be extended to cross-disciplinary doctoral education, as it is certainly important to reflect on the choice of cross-disciplinarity as well.

Knowledge acquisition, arenas and networks: Of the four research milieus investigated, only one offered courses explicitly addressing cross-disciplinarity, which could facilitate the PhD candidates' development of a theoretical understanding of different forms and thinking of cross-disciplinarity. This meta-approach to cross-disciplinarity also benefits the research

milieu as such by providing common concepts that might limit the conceptual misunderstandings that some PhD candidates describe in their communication with their supervisors. Another observation is that informal and voluntary activities organised by PhD candidates are common. This is not a problem in itself, but it might be a problem if it stems from a perceived lack in the research milieu's ability to address vital needs of the PhD candidates. There is a risk that PhD candidates are left unaided without sufficient support and guidance. Self-organised activities are good from a socialisation perspective, particularly if the supervisors and the senior researchers in the research milieus also participate, but it is risky to count on this happening spontaneously and there is no guarantee that vital issues will be addressed through this type of organisation if it takes place without guidance. Instead, this needs to be strategically and systematically handled in line with the objectives of the research milieu. Both these matters, i.e. the offering of courses and network arenas, lay the foundation for developing a conceptual apparatus and a common understanding across the research milieu that benefit the PhD candidates. Accordingly, research milieus and supervisors should plan vital components such as seminars and other activities, and not let PhD candidates do all the organisation informally.

Supervision and the research milieu: In a cross-disciplinary research setting, different backgrounds can be both a strength and a weakness, and this needs to be explicitly discussed by supervisors. A distinction could also be made between the milieu, on one hand, which should be characterised by cross-disciplinarity, and the supervisors on the other, which could be less cross-disciplinary, depending on the needs of the PhD project and the research approach followed. As collaboration is essential and inherent in cross-disciplinary research, it has the potential to build confidence while at the same time offering good collaborative training that may lay the foundation for the PhD candidates' successful future research careers.

Cross-disciplinary research approaches are vital components in contemporary research addressing societal challenges. Much debate has focused on different forms of cross-disciplinarity, when it has the best potential, and whether it might inhibit traditional disciplinary ways of undertaking an academic career. In practice, cross-disciplinarity influences much doctoral education. Because cross-disciplinarity to various degrees challenges conventional research practices and the established institutional structures of

universities, we argue that attention has to be paid to the experiences of PhD candidates, as their experiences can improve the offering of doctoral education in cross-disciplinary settings. One key finding is that PhD candidates are more comfortable when their education has involved meta-communication about conceptual approaches and experiences of conducting cross-disciplinary research. This calls for research milieus' providing doctoral education in cross-disciplinary settings to take a deliberative approach. This will both benefit the PhD candidates and the research milieus, and is central in the socialisation process of the next cadre of researchers and for the future of cross-disciplinary research.

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Interviews

The Centre for Regional Studies (CRS):

PhD candidate 1 (completed doctoral education), face-to-face, 27 August 2015, duration 52:05.

PhD candidate 2 (ongoing doctoral education), face-to-face, 20 May 2015, duration 48:22.

PhD candidate 3 (ongoing doctoral education), face-to-face, 29 May 2015, duration 35:30.

Risk and Environmental Studies (RES):

PhD candidate 1 (ongoing doctoral education), face-to-face, 21 May 2015, duration 51:44.

PhD candidate 2 (ongoing doctoral education), face-to-face, 5 June 2015, duration 48:08.

PhD candidate 3 (ongoing doctoral education), face-to-face, 19 May 2015, duration 38:38.

PhD candidate 4 (ongoing doctoral education), face-to-face, 16 June 2015, duration 58:10.

The project Adaptations of natural resource-based communities to climatic and societal changes - Sami reindeer herding in the past, present and future, at Umeå University:

PhD candidate 1 (completed doctoral education), face-to-face, 8 June 2015, duration 51:47.

PhD candidate 2 (completed doctoral education), Skype, 11 June 2015, duration 40:57.

PhD candidate 3 (completed doctoral education), telephone, 20 May 2015, duration 38:49.

The Eco hydrology and water resource management:

PhD candidate 1 (ongoing doctoral education), face-to-face, 7 May 2015, duration 32:05.

PhD candidate 2 (ongoing doctoral education), face-to-face, 7 May 2015, duration 37:16.

PhD candidate 3 (ongoing doctoral education), face-to-face, 7 May 2015, duration 45:32.

PhD candidate 4 (ongoing doctoral education), telephone, 9 June 2015, duration 43:24.

”We need a kind of forum where you actually discuss ... what cross-disciplinarity is, what sort of cross-disciplinarity we are dealing with, how we define it and how we practise it”

Cross-disciplinarity shapes much research today and many PhD candidates are engaged in this research. The doctoral education is a formative phase in a scientist’s intellectual development. Despite a large body of research about cross-disciplinarity, less attention has focused on how cross-disciplinarity shapes doctoral education.

This report explores the organisation of doctoral education in four cross-disciplinary research milieus and the experiences of 14 PhD candidates enrolled in these milieus.

One key finding is that PhD candidates are more comfortable when their education has involved meta-communication about conceptual approaches and experiences of conducting cross-disciplinary research. This calls for research milieus’ providing doctoral education in cross-disciplinary settings to take a deliberative approach. This will both benefit the PhD candidates and the research milieus, and is central in the socialisation process of the next cadre of researchers and for the future of cross-disciplinary research.

978-91-7867-031-4 tryck)
978-91-7867-036-9 (pdf)