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The formation of successful physics students

Discourse and identity perspectives on university physics

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Abstract
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In university physics education, unequal student participation has always been an issue. An example is the fact that men constitute 70–80% of the student body in most countries. In recent years, physics education research has started to explore issues of participation, diversity, and identity, but more research and theoretical and methodological development is needed. The work presented in this thesis adopts a discursive perspective on students' physics identity, building on developments in gender studies and related fields. Focusing on several important steps in physics education, the study explores what it means to become a physicist by asking how norms about being a successful physics student are constructed in the discourses of the education. The methodology is qualitative and interpretative, using participant observation and interviews to explore classroom discourse and student narratives. These theoretical and methodological tools combined with a detailed focus on physics education practice, provide a framework for a deeper understanding of identity in physics. A general conclusion of this study is that physics courses, when taught from a narrow physics perspective, may limit the possibilities for identification for many students. For example, engineering students on less physics-oriented programmes had difficulties seeing electromagnetism as significant for their vocational identity. Similar results occurred in quantum mechanics, where a strong focus on calculating can alienate some students. Concurrent with the particular appeal that quantum mechanics can have in attracting students to physics, a mismatch between expectations and course practice can cause an identity crisis for students investing in an identity as a quantum physicist. For physics master's students, finding a place in physics meant negotiating norms about intelligence and "nerdiness". These common and gendered stereotypical attributions for physicists took on specific significance in relation to subject choice in physics. More theoretical and pure physics directions were implicitly accorded higher status and seen as requiring more intelligence, but at the same time could also be positioned as more nerdy. The study's outcomes provide input to physics instructors and departments who want to develop more inclusive and diverse physics education, as well as theoretical and methodological resources for further research.

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Till Staffan

List of papers

This thesis is based on the following papers, which are referred to in the text by their roman numerals. My specific contributions are outlined below each paper.

I Andersson, S., & Johansson, A. (2016). Gender gap or program gap? Students' negotiations of study practice in a course in electromagnetism. *Physical Review Physics Education Research*, 12(2), 020112.

Staffan Andersson proposed the idea and collected the data. We analysed the material and wrote the paper together.

II Johansson, A., Andersson, S., Salminen-Karlsson, M., & Elmgren, M. (2018). "Shut up and calculate": the available discursive positions in quantum physics courses. *Cultural Studies of Science Education*, 13(1), 205-226.

The paper was published ahead of print in August 2016. I proposed the idea. The project was designed in a collaborative process led by me. I conducted the observations and interviews. Analysis and writing was done collaboratively but led by me.

III Johansson, A. (2016). Analyzing discourse and identity in physics education: Methodological considerations. In D. L. Jones, L. Ding, & A. L. Traxler (Eds.), *2016 Physics Education Research Conference Proceedings* (pp. 180–183). Sacramento, CA: American Association of Physics Teachers.

I proposed the idea for the paper and wrote it.

IV Johansson, A. (2018). Undergraduate quantum mechanics: Lost opportunities for engaging motivated students? *European Journal of Physics*, 39(2), 025705.

I proposed the idea for the project. I designed the research, planned and conducted the interviews. I analysed the interview material and wrote the paper with feedback from supervisors and others.

V Johansson A. (submitted) *Negotiating intelligence, nerdiness, and status in physics master's studies*

I proposed the idea for the project. I designed the research, planned and conducted the interviews. I analysed the interviews, discussed the analysis with supervisors and others, and wrote the paper with feedback from supervisors.

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Contents

Glossary

What follows are short descriptions of theoretical concepts and abbreviations used in the text. Some of the concepts explained here have many definitions and are used in many contexts. These descriptions are intended to clarify how I use them in this thesis.

AAPT American Association of Physics Teachers

AJP *American Journal of Physics*

discourse Means "talk" or "conversation" but in the context of poststructuralist theory, related traditions, and in this thesis takes on a specific but also wider meaning of "institutionalised use of language and language-like sign systems" (Davies & Harré, 1990, p. 45). This definition emphasizes how all communication draws from already established structures. Importantly, in social constructionism, discourse defines how we see the world. "To know anything is to know in terms of one or more discourses." (Davies & Harré, 1990, p. 45)

EJP *European Journal of Physics*

gender Generally means "social sex", and in this thesis is interpreted in a social constructionist tradition. This means recognizing that the division of people into men and women, and the attributes or behaviours traditionally expected of the "two genders" are in no sense fundamental, and subject to change. It does not mean that gender is unimportant in society, many people are identified and identify themselves as men or women, and many inequalities are based on gender. I reserve a similar social constructionist wariness to other categories such as ethnicity.

identity In this thesis, identity refers to *social* identity, how people appear to others. My focus is on context specific identities, for example what is implied in being a "physics person". I recognize that identity is a problematic concept with many meanings and often prefer to use "position" or "subject position" instead. This is discussed at length in Chapter 3.

PER (Physics Education Research) My research field. Deals with research about physics education primarily at university level. The Swedish term: *fysikdidaktik*, is often interpreted as both a wider (in that it implies no focus on a specific level) and narrower field (in that it implies a focus only on the learning of physics concepts).

PERC (Physics Education Research Conference) Annual conference held for the US and international PER community as a continuation of the teaching-oriented AAPT conference. Much of the most current work in PER is presented there and published in the proceedings.

poststructuralism Represents an intellectual tradition rooted in 20th century structuralism, but emphasizing the indeterminacy and fluidity of social structures. In this thesis, I mostly use the term to refer to accounts of how discourse embeds power and defines identities in society, developed by Michel Foucault and others.

power The aspect of power in society discussed in this thesis is primarily the imposition of social norms in discourse. Power lies in the production, definition and limiting of possibilities for identification in discourse.

PRPER *Physical Review Physics Education Research*

social constructionism A tradition of social theory emphasizing the historical construction of the social world. An important part of this theory is the question of knowledge, that what we experience is filtered through our historically conditioned expectations. The poststructuralist vein of this tradition emphasizes the fluidity and power inherent in social construction.

STEM Science, Technology, Engineering and Mathematics

subject position Denotes the points of attachment for appearing as a person, a subject, in discourse. Its use emphasizes how there is no self-evident way of being a person, that we must adopt a position established in discourse to be intelligible to others. I have often preferred to refer to positions in discourse rather than identities, to emphasize the social construction of these positions and that they should not be viewed as properties of a person.

Preface

Twelve years ago, I started my university education on the physics programme at Uppsala University, along with about 30 other eager students. Now, about half of those people have a degree in physics. That can be considered a pretty good result; physics in Sweden is a subject with a moderate degree of programme completion. However, the story does not end there. The question of becoming a physicist is not only a question of getting a degree, it is also a question of *becoming someone*, and what strikes me as particularly intriguing in this context is that even though they may have a degree in physics, my former classmates may not necessarily see themselves as physicists. Even if they do, few have the same picture of physics, physicists and themselves that they had when they started at the university. Surprisingly, several of the people who initially aimed for a research career in physics and were successful in their studies have changed directions and are now working in other areas. My own path of studies has not been so straight either, moving from a theoretical physics interest, to humanities and social science and back to study physics from a meta-perspective in the form of physics eduction research. All this raises questions of what it *means* to become a physicist, and how this affects who feels attracted to, welcomed in, and encouraged by physics. Who do you become when you become a physicist?

Asking these kinds of questions means looking at issues of identity and culture in physics, that is, putting the *sociocultural* aspects of education in the spotlight. In physics education research, these questions have not been foregrounded much until recent years, and my aim with this work has been to contribute to and develop research about the sociocultural aspects of physics education. By combining my grounding in physics and gender studies I have worked to bring new theoretical and methodological tools to physics education research, which will hopefully enable us to better answer some of the pressing questions about identity and diversity in physics. In a sense, I have been using these tools to delve into my own and my friends' varied experiences in physics education, albeit through the eyes of the helpful students and teachers who have participated in my research. I want to formulate a critical picture of physics education as a sociocultural practice, and discuss how "success" in physics can be defined in more terms than only passing exams and getting degrees. In the end, my goal is to increase understanding of what happens in physics education and what it means to become a physicist, to enable more informed efforts towards a more diverse and equitable physics.

1. Introduction

Questions of diversity and identity in physics education have been raised from many standpoints in research and policy. For example, the decreasing interest for studying science among students' in western countries (Schreiner, 2006; Sikora & Pokropek, 2012) has been a growing concern in recent decades (European Commission, 2004; President's Council of Advisors on Science and Technology, 2012). This concern relates to both a general decline in interest in science and technical/scientific programmes, and an ongoing lack of diversity, where women and minority groups are still underrepresented (OECD, 2017b; UNESCO, 2015, chapter 3). For example, the proportion of women in physics undergraduate education is still around 20–30 percent in many countries (American Physical Society, 2018; OECD, 2017a; Universitetskanslerämbetet, 2016). The discussions about science participation can often be characterized as a discussion of a "lack", for example of women, conceptualized in what has been called a "deficit framework" (Traxler, Cid, Blue & Barthelemy, 2016; Zeidler, 2014). An example of this idea is the notion that "Europe needs more scientists" (European Commission, 2004). From this perspective, the issue seems to be how to get more (of certain kinds of) people into science. Quite apart from questions of social justice and increasing the scientific work force, research has also shown how diverse research groups are more productive (GEDII, 2018). Despite this knowledge, women and minorities are still discriminated against within science, for example by unequal practices in hiring and promotion, where women reach a glass ceiling (Rosser, 2004) but also by direct sexual harassment (National Academies of Sciences, Engineering, and Medicine, 2018).

In physics education research (PER), the primary matter of concern has been the cognitive learning of students who are already studying physics at the university, although equity issues in the form of "gender gaps" in student learning and attitudes have also been documented and analysed (Madsen, McKagan & Sayre, 2013; Wilcox & Lewandowski, 2016a). An increased attention to the sociocultural aspects of physics education is indicated by the recent inclusion of resources from university recruitment and retention research (Seymour & Hewitt, 1997; Tinto, 2006) to further explore how students become engaged in and navigate physics studies (Bøe & Henriksen, 2013; Forsman, Linder, Moll, Fraser & Andersson, 2014; Forsman, Mann, Linder & van den Bogaard, 2014; Johannsen, Rump & Linder, 2013).

Another expression of the growing concern for sociocultural aspects in physics education is the increasing use of social identity concepts as a way

of connecting the social environment to issues such as students' attitudes and choices (Holmegaard, 2015; Tytler, 2014). Importantly, using identity frameworks in a nuanced manner has been suggested as one method of moving away from a focus on gender difference and the lack of women or women's poor performance (Traxler et al., 2016). In PER, identity frameworks have often focused on helping underrepresented students in developing a physics identity. However, this approach risks not taking the complexity and power-relations inherent in identity issues into account. To alleviate this problem, the research presented in this thesis draws from a notion of identity as constructed in discourse, common in gender studies and related fields. In this way it aims to broaden the theoretical and methodological approaches to identity used in PER, where such approaches have not been attempted to any great extent.

By introducing and developing theory and methodology, this thesis contributes to the continuous theoretical and methodological development of PER, an almost 40 year old research field. In many respects, PER has always been multidisciplinary, in that its practitioners are often situated within physics departments and combine an in-depth knowledge of physics with other educational research approaches. PER has been successful in detailing students' learning of physics and effecting change in the teaching practices at many institutions. Over the years, PER has seen an expansion of topics and theories, including more elaborate psychological and cognitive theories of students' learning, and has expanded to cover ever more areas of physics content. Taking the multidisciplinarity of PER seriously means basing research and teaching on "solid foundations" in physics and in other educational studies (van Aalst, 2000, p. 67). With a growing interest for studying identity and social issues in physics comes a need for informing this research with theories and approaches that have already been developed to deal with these issues in the social sciences and humanities.

The research presented in this thesis is situated at an interdisciplinary crossroads between PER and gender studies, reflected in my background, in the composition of the supervisory team, the research process and the genres of writing in the five papers. The aim has been to address issues of diversity and identity in nuanced ways by bringing these two research traditions into fruitful dialogue. One part of doing this involves discussing the role of the culture of physics in physics education. Thus, while PER, as a form of Discipline-Based Education Research (DBER), can be characterized as investigating "learning and teaching in a discipline using a range of methods with deep grounding in the discipline's priorities, worldview, knowledge, and practices" (National Research Council, 2012, p. 9) my aim in this thesis is to also see beyond the priorities and worldview of physics in order to allow a discussion of the goals of physics education. My approach for doing this is to adopt the critical research standpoint used in most gender research and apply it within physics education.

A central aspect of this approach to investigating diversity and inequity in science is to address problems at the institutional level or attitudes in society as a whole. Such structural factors can be seen as "excluding" or "repressing" certain students, making science still "lack" these people. However, drawing on Michel Foucault (1975/1995, p. 194), power can be seen not simply in terms of *repressing* certain individuals, but also in terms of *producing* our conception of reality and the individuals inhabiting it. Thus, in this thesis, I want to reformulate the questions of student recruitment, retention and success in physics by asking what culture and identities are (re-)produced in physics departments. This shifts the focus from a deficit model where physics lacks certain people or certain people are framed as lacking ability or interests to a focus on scientific culture itself.

In this way, I turn the deficit-oriented question of who is a successful physics student into a question about the conditions and expectations that define success, and how successful physics students are *formed* in the discursive practices of physics education. To what extent does this formation promote diversity in physics?

1.1 Research aims

Motivated by research on gender gaps and other gaps in students' results, interests, attitudes and study choice relating to physics education, I want to direct the attention of my research to the culture of physics (inspired by forerunners such as Traweek, 1988 and Hasse, 2002), and the possibilities this culture provides for student identifications. In this way, I aim to merge critical perspectives on identity in science in relation to minoritized groups, with the idea of students' development of physics identities. I intend to take a critical approach to the construction of the successful physics student and to what positions are normative in physics culture, rather than only asking who is attracted to physics or who performs better or worse. In doing this, I aim to avoid so called "gap gazing" and "deficit models" (Traxler et al., 2016).

With these perspectives, the overarching aims for the thesis are threefold:

1. To contribute to the understanding of diversity issues in physics.
2. To introduce and develop critical identity perspectives grounded in discourse theory to physics education research.
3. In particular, to do this by addressing questions such as:
    - *How is a successful physics student formed?*
    - *Which subject positions are made available for students in the discourses of physics education?*

1.2 Development of specific research questions

The research reported in this thesis was conducted in three empirical projects, and reported in five papers (see Table 1.1). The projects all provide different pieces to the puzzles presented in the aims of the thesis in Section 1.1 above.

Table 1.1. *The projects conducted for the thesis, a description of each of the data sets used and the papers that each project was reported in. A more detailed picture is given in Figure 5.1*

Projects	Data	Papers
Project 1	Interviews and grade data	Paper I
Project 2	Participant observation and interviews	Paper II
—	Literature review	Paper III
Project 3	Interviews	Paper IV Paper V

The first project, reported in Paper I, deals with a diverse group of students (engineering students and physics programme students), taking an introductory Electromagnetism course at a major Swedish university. While the initial motivation for the project was to investigate an apparently consistent gender gap in students' achievements in the course, the project developed to look more widely into students' identifications, in relation to study programmes and their education in general. This project then gives insight into how a wide selection of students taking physics, not necessarily as their main subject, experience the same physics classes. The specific research questions for this project are:

I.1 How do students make sense of their experiences of the course in relation to gender, programme, etc.? What discourses are drawn upon? How is identity constructed?

I.2 Drawing on this analysis, how can the measured gender gap in exam results be conceptualized or explained in more nuanced ways than "men perform better than women"?

The second project, reported in Paper II, highlights the formation of physics students further down the path to becoming a physicist by examining introductory quantum mechanics, a course generally taken by students who will earn a degree in physics. While the first project focused on students' sense-making of the course and their social context, this project was conducted primarily through classroom observations and focused on how the discourse within courses sets the frames for context-specific physics identifications. In this way, it gives an example of how specific choices made in physics teaching can provide specific possibilities for student identifications.

Rather than formulated as a number of specific research questions, the aim of Paper II is described as exploring available discursive positions in under-

graduate courses in quantum physics. In the discussion of this thesis, I will disentangle this aim and formulate it in terms of the following questions:

II.1 What practices of doing physics and what discursive positions for enacting a legitimate or good quantum physics student are made available in the discourse of quantum physics courses?

II.2 How do these positions match student expectations and what can they imply about wider physics practice?

Paper III is a theoretical position paper analysing the approaches to studying identity taken in Papers I and II. This is discussed in relation to other common approaches in PER. No additional *empirical* research questions were formulated for this paper, rather the focus is *theoretical* and *methodological*.

The findings of the first two projects motivated the continued development of the thesis work. First, while Paper II focused on the possibilities given in quantum mechanics courses, it would also be worthwhile to delve deeper into student identifications in relation to taking the course. Second, taken together, the first three papers focused on undergraduate courses, but investigating identity constructions further down the path to becoming a physicist would be a valuable way of enriching the picture. With this in mind, project 3, focusing on the master's level in physics education, was designed to reach some further answers to these questions. The project was conducted as a mix of participant observation and more formal interviews with master's students in physics. The results reported in Papers IV and V are based on analyses of the interview material.

For Paper IV, the aim of getting a deeper insight into how quantum mechanics itself can shape students identifications in physics was attended to by analysing master's students descriptions of their experiences of taking the course The research question for this paper is:

IV.1 How have students' encounters with their first quantum mechanics course influenced their orientation and identification in physics?

Paper V aims at exploring how the norms in physics education can be experienced by students and how this comes to matter for their negotiations of their own place within it. In the analysis of the interviews with the master's students, the interviewees' negotiations of norms in physics were focused on in relation to perceived discourses about stereotypical physicists inside and outside the university. Importantly, this analysis, like Paper I, addresses differences in identifications between physics specializations. The general research questions addressed in this paper are:

V.1 What common discourses around being a physics or science person do the master's students draw on when narrating their experiences of physics studies?

V.2 How do the students negotiate their positions in physics in relation to discourses about ideal or stereotypical physicists and implicit evaluations of physics specializations?

In the paper, this is reformulated as a more specific aim of exploring "the negotiations of positions in physics master's students' trajectories towards becoming physicists in relation to perceived norms about physics and physicists."

1.3 Structure of the thesis

The body of the thesis is divided into eight chapters, aimed at developing the motivations and background for the research reported in the papers, describing the research processes and discussing the results. In Chapter 2, I will provide an overview of the research traditions my thesis contributes to, and motivate why this contribution is needed. The chapter describes the general development of research in physics education, how recent years have seen an increasing interest in studying identity issues, but how these efforts could be extended by theoretical and methodological frameworks that can give a more complete picture of the social issues at hand in physics education. Chapter 3 presents the background for such a theoretical framework, discussing how identity can be conceptualized and proposing that a poststructuralist understanding of identity as constituted in discourse presents a valuable tool for studies of identity more attentive to norms and power. Following this, Chapter 4 describes the methodological traditions which I have drawn from in my research, namely interpretative discourse analysis, ethnography and interview techniques. More detail about how the research presented in the thesis has been conducted in practice is given in Chapter 5, which describes the data collection and analysis processes. Chapter 6 then summarizes the findings from each of the papers. In Chapter 7, these results are brought into dialogue in an overarching discussion that brings out a few of the central themes of the research, as well as some of the implications for practice and further research. Chapter 8 presents a succinct summary of the contributions this thesis brings to the field of physics education research, and how this applies to physics education practice. Chapter 9 concludes the story.

2. Situating my research

This thesis is situated in the field of physics education research (PER), but also draws from the related science education research field. This chapter describes the development of these fields, presenting a general overview of PER and an in-depth review of PER work on identity.

2.1 Development of research in science education

Research in physics education, and in science education in general, started to expand in the decades after World War II. In an American context, this is connected to the educational reforms initiated in the US after the successful launch of Sputnik, when scientists were urged to contribute to a renewed science education that would make Americans more prepared to compete with the Soviet Union in the "science race" (National Research Council, 2012, p. 20). After this, science education research, with a primary focus on secondary education, has gone through several waves of resurging interest. According to De Jong (2007), these waves can be characterized by the different theoretical frameworks emerging at the time. The first, post-Sputnik, wave, was influenced by "descriptive behaviourism" and "cognitive development" theories; the second, after the disappointments of the first wave and the 1983 publication of the American report "A Nation At Risk", was influenced by "cognitive psychology" and "information-processing", and brought active learning onto the scene; the third, and still ongoing wave, (2000s) is influenced by "social constructivist" and "sociocultural" perspectives (De Jong, 2007, pp. 16–17). Despite these developments and various theoretical influences, the majority of research in science education, in contrast to other educational research, draws from a natural sciences inspired, experimental paradigm. In this paradigm, the means of improving education are understood in terms of doing experiments or other kinds of empirical studies to determine what measures best increase students' learning and interest in science. This is most obvious in the political policies urging for better STEM (Science, Technology, Engineering and Mathematics) education, which calls for evidence-based initiatives, and in the research aligned with these (see discussions in Mendick, Berge & Danielsson, 2017; Treagust, Won & Duit, 2014; Zeidler, 2014). What students should learn is often taken for granted in this context. Thus, although challenged for example by social constructivist perspectives, a large part of science education can still be viewed as working in a "post-positivist" paradigm (Treagust

et al., 2014). I will discuss research paradigms further in Section 2.4.2, but first I need to outline the development and current status of physics education research.

2.2 Physics education research

The post-Sputnik curriculum developments also concerned the recruitment and education of science professionals at universities, but it was not until the late 1970s that in-depth explorations of student learning of university physics began, as researchers at the University of Washington started investigating students' understandings of kinematics (McDermott, 2001; Trowbridge & McDermott, 1980, 1981). Since then, physics education research has grown into a wide and independent field, mostly focusing on education at the undergraduate level and with most research still done in the US where up to 100 different PER groups exist. In the rest of the world, 15 more groups are registered on the *PER Central* web page, published by the American Association of Physics Teachers, (AAPT, 2015), but several more exist, although they do not necessarily communicate widely with the international (English-speaking and US-centred) PER community. For example, several groups in Germany conduct PER (Physikdidaktik) but publish almost exclusively in German.

PER is an example of Discipline-Based Education Research (DBER), that is, research into teaching and learning in a specific discipline (of science and engineering), where the researchers combine an extensive knowledge of their discipline with methods and theories from, among other fields, psychology, educational theory, and anthropology (National Research Council, 2012, p. 10). As is common for DBER, PER groups are often situated at physics departments, although different arrangements and collaborations, in particular with education departments, are common (National Research Council, 2012, p. 21). Being situated at physics departments has been argued as necessary for the success of PER, mainly because "education research conducted by physicists in physics departments is more credible, more accessible, and, in general, more relevant to physics faculty than that conducted in colleges of education or departments of psychology (although the conclusions are typically consistent)" (Heron & Meltzer, 2005, p. 391). However, being situated in a physics department is not always easy for researchers doing interdisciplinary work, and one of the obstacles discussed by PER researchers is the struggle to be accepted, both as physicists (Barthelemy, Henderson & Grunert, 2013, p. 10), and as legitimate researchers, since teaching and learning has often been viewed by more conservative physicists as more of an art than a science (Beichner, 2009; Cummings, 2011, p. 7; McDermott, 2001). Another problem can be that PER researchers are often not accepted as serious researchers on the same footing as their departmental colleagues, but instead are often viewed as "resource people whose major responsibility is to provide local support for instruction

rather than to conduct scholarly research" (Heron & Meltzer, 2005, p. 392). That PER is an undeniably integral part of the research in physics departments is however affirmed by the American Physical Society, which issued a statement to this effect in 1999 (American Physical Society, 1999).

Similar to science education research, PER has traditionally approached the problems of teaching and learning in physics with methods inherited from physics and natural sciences (Heron & Meltzer, 2005), for example manifested in a preference for "papers in which the approach and the rules of evidence are close to those traditional in the physics community" (McDermott & Redish, 1999, p. 757). While this focus on measurement, experiment and statistical validity has made PER more acceptable to physicists, it has perhaps at the same time made it less attentive to perspectives and methods from the social side of educational research (van Aalst, 2000). One indication of this tendency is that PER has borrowed methods and results from cognitive psychology and neuroscience more often than from other educational fields (McDermott & Redish, 1999, p. 765).

In the following sections, I will describe research pertaining to two concerns of physics education research. First, the problem that *most students do not understand physics as well as we would like them to*, and second, that *students' performance, experiences and inclusion in physics differ in apparently unjust ways*. While PER has primarily been concerned with the former of these problems, a growing subfield attends to the latter problem and focuses on questions of diversity, equity, access, and inclusion in PER. My contribution is primarily aimed towards this field. Section 2.3 deals with research concerned with the first, *cognitive*, concern and Section 2.5 with the second, *sociocultural*, concern.

2.3 Major areas of contemporary research in PER

The traditional concern driving physics education has been the question of how students come to understand physics, and how learning can be improved. Throughout the years, this research has continuously expanded to include new research techniques, questions and theoretical frameworks, often imported from fields outside of PER such as psychology or educational theory. Coupled to this development of topics of research are the design of survey tools to assess students' knowledge, and the development of research-based curricula that can better assist students' learning.

2.3.1 Conceptual understanding

As described above, PER began with investigations of how students come to understand kinematics. Since then, a large part of the research in physics education has been concerned with how students learn (or do not learn) physics

concepts. These kinds of studies were initially largely based around identifying students' "misconceptions" about physics concepts and resulted in extensive "catalogs" of possible misconceptions (Docktor & Mestre, 2014, p. 2). The term "misconceptions" has been debated and through the years "modified to 'student difficulties,' 'naïve conceptions,' or 'intuitive understanding' in an attempt (which was not entirely successful) to minimize the negative connotations of the original name" (Beichner, 2009, p. 13). Even though using "misconception" might be considered too "degrading" to students' everyday thinking, the term is still used today (see e.g. Kaltakci-Gurel, Eryilmaz & McDermott, 2016; Scott & Schumayer, 2018; Suarez, Kahan, Zavala & Marti, 2017; Temiz & Yavuz, 2014).

Successful methods for probing students' conceptual understanding have been individual "demonstration interviews", developed by the University of Washington PER-group and modelled on Piaget's clinical interviews, and "concept inventories", questionnaires distributed to assess the conceptual understanding of large groups of students (Cummings, 2011, p. 12; McDermott, 2001, p. 1128). Studies of students' conceptual understanding started out as empirical investigations not employing extensive theoretical frameworks (McDermott & Redish, 1999, p. 765), but over time a number of different frameworks for describing how students come to understand (or not understand) science concepts have been proposed and used (Docktor & Mestre, 2014, p. 3). Some of the main theories are the "conceptual change"-theory first put forward by Posner, Strike, Hewson and Gertzog (1982) and different "knowledge in pieces"-views (diSessa, 1988), like the resources view of Hammer and others (Hammer, Elby, Scherr & Redish, 2005); the "facets"-view of Minstrell (1992); and the "ontological categories"-view of Chi and others (Chi & Slotta, 1993). While the earlier theories described students' conceptions in relatively stable terms, as naive theories or alternative frameworks, this was criticized for not taking the context into account (Linder, 1993a), among other things. Much recent research has instead focused on "microprocesses of change", in line with the resources framework, and e.g. viewed students' understandings as reflecting "multiple local coherences" (Frank & Scherr, 2012, p. 1).

The research on conceptual understanding started with concepts in the introductory courses of college physics, for instance kinematics and dynamics (Trowbridge & McDermott, 1980, 1981; Viennot, 1979). Interpretations of graphs was also an early area of interest (McDermott, Rosenquist & van Zee, 1987), along with electricity and magnetism (Cohen, Eylon & Ganiel, 1983; Fredette & Clement, 1981; Fredette & Lochhead, 1980) and sound (Linder, 1993b; Linder & Erickson, 1989). Studies exploring understanding of more advanced physics topics have been undertaken more widely in recent years, even though some early examples exist. Most focus here has been put on special relativity (Hewson, 1982; Scherr, 2007; Scherr, Shaffer & Vokos, 2001) and quantum mechanics. (Fischler & Lichtfeldt, 1992; Johnston, Crawford & Fletcher, 1998; Wittmann, Steinberg & Redish, 2002). Extensive reviews of

students' understanding of quantum mechanics concepts are available in Falk (2007), Singh and Marshman (2015), and Krijtenburg-Lewerissa, Pol, Brinkman and van Joolingen (2017). Modern physics has generally been found to possibly involve difficult conceptual transitions for students, but in Papers II and IV I add to this picture by showing how taking quantum mechanics in particular can also have strong affective and social effects for students.

2.3.2 Problem solving, representations and semiotic resources

Another large area of PER is research on problem solving. It is an area centered in practice: physics involves a lot of problem solving, and this is a craft that is often difficult to learn for students. The first studies in this area examined how students solved or categorized problems compared to experts (Chi, Feltovich & Glaser, 1981; Larkin, McDermott, Simon & Simon, 1980; see Docktor & Mestre, 2014, for a longer discussion). These comparisons grew into discussions of how successful scientists think (Van Heuvelen, 1991) and into promoting the learning of what is often called "expert-like thinking" (Adams & Wieman, 2011).

An important discussion in this area concerns the definition of "problem solving". Many authors have pointed out that solving "end-of-chapter problems" from physics textbooks does not cover the whole range of skills required for scientific problem solving (Hsu, Brewe, Foster & Harper, 2004; Maloney, 2011). In addition, the common way that exercises are presented and used for examinations in physics education may encourage a "plug-and-chug" attitude to solving problems for students (Tuminaro, 2004). Research has pointed to how more complex reasoning and "metacognition" (Schoenfeld, 1992) is necessary for successful, more expert-like, scientific problem solving (Maloney, 2011). Even though instructors are often aware of these problems, it has proved difficult to transform exercises from the traditional, easily examinable, plug-and-chug problems to more authentic ones (Yerushalmi, Cohen, Heller, Heller & Henderson, 2010).

Some of the research on problem solving has developed into investigations of how representations of physical concepts are used in physics and physics education. These studies, more common in the last decade, have examined what representations are used in problem-solving, how students translate between different representations (often in contrast to experts), and also what using specific representations entails (Docktor & Mestre, 2014, p. 7; Ibrahim & Rebello, 2012; Kohl & Finkelstein, 2008; Meltzer, 2005). Newer developments in this area have brought in results from linguistics and social semiotics to explore the utilization of "semiotic resources" in physics learning, arguing that different resources afford different understandings of physics concepts (Fredlund, Airey & Linder, 2012). This can for example concern the use of gestures (Gregorcic, Planinsic & Etkina, 2017) or interactive soft-

ware (Euler & Gregorcic, 2018). Importantly however, this strand of research also argues that students need to master a critical constellation of resources to achieve fluency in the knowledge of the discipline (Airey & Linder, 2009; Volkwyn, Airey, Gregorcic, Heijkensköld & Linder, 2018).

2.3.3 Students' attitudes and beliefs

Like other science education researchers PER researchers have been interested in studying students' and teachers' attitudes and beliefs. This research aims to understand for example how students and teachers view physics learning, general attitudes towards science, and what epistemologies students use to make sense of physics. These questions are most often evaluated in the light of what may lead to the best learning of physics (Docktor & Mestre, 2014, p. 35). Both quantitative and qualitative methods have been used to explore these issues, with several large surveys developed to assess student populations (see Section 2.3.5), but also interview studies with students (Hammer, 1994) and teachers (Henderson & Dancy, 2007). These studies have shown that students learning physics often encounter problems relating to what learning approaches and epistemological views they hold (Elby, 2001, 2010). One example of this is that "students perceive 'trying to understand physics well' to be a significantly different activity from 'trying to do well in the course'" (Elby, 1999, p. 52). The problems have also in this case been formulated as a transition from novice to expert "epistemological skills" (Bing & Redish, 2012). An unsettling result from some of these studies is that students' beliefs about learning physics often do not improve when taking standard courses, and at times even deteriorate, perhaps related to plug-and-chug attitudes being encouraged by standard instruction (Madsen, McKagan & Sayre, 2015).

2.3.4 Development of teaching and curricula

Along with investigating physics education, PER naturally aims at improving it. Several teaching methods, teaching materials, and curricula have been developed and tested by PER researchers and people inspired by PER, and the methods have been more or less closely related to the research. One of the more influential methods is *Peer Instruction*, popularized as a way of reforming lectures by Eric Mazur and others (Crouch & Mazur, 2001; Crouch, Watkins, Fagen & Mazur, 2007; Mazur, 1997). This method is informed by PER in using the central fact that *interactive engagement* generally leads to better conceptual understanding for students (as has been shown in several large surveys, see Freeman et al., 2014; Hake, 1998) and in using knowledge about common "alternative conceptions" in creating questions. The PER group at the University of Washington have developed two influential curricula, closely based on their research on students' conceptual understanding: the lab-based

Physics by Inquiry and the model for reformed tutorials *Tutorials in Physics* (McDermott, 2001; McDermott & Shaffer, 2002; McDermott, Shaffer & Rosenquist, 1996).

Other curricula and methods developed by PER researchers include the almost completely lab-based *Investigative Science Learning Environment* (Etkina et al., 2010; Etkina & Van Heuvelen, 2007; Van Heuvelen & Etkina, 2005) and other methods reforming the whole classroom like *Studio Physics* (Cummings, Marx, Thornton & Kuhl, 1999; Wilson, 1994) and more recently SCALE-UP (Beichner et al., 2007). A few general physics textbooks have also been based on research in PER, e.g. *Understanding Physics* (Cummings, Laws, Redish & Cooney, 2004) and *Matter and Interactions* (Chabay & Sherwood, 2007, 2010).

2.3.5 Tools for assessing student understanding, attitudes, and epistemology

PER researchers have developed several tools for assessing students, which enable comparisons of the efficiency of different educational strategies. These tools mainly consist of tests or questionnaires distributed before and after teaching specific subjects. The surveys for assessing students' understanding of different physics concepts are generally referred to as "concept inventories". A few of the more widely used are:

- Mechanics: the *Force Concept Inventory* (FCI, Hestenes, Wells & Swackhamer, 1992), the *Force and Motion Conceptual Evaluation* (FMCE, Thornton & Sokoloff, 1998), and the *Test of Understanding Graphs in Kinematics* (TUG-K, Beichner, 1994).
- Electricity and magnetism: *Conceptual Survey in Electricity and Magnetism* (CSEM, Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2001), *Brief Electricity and Magnetism Assessment* (BEMA, Ding, Chabay, Sherwood & Beichner, 2006), and *Colorado Upper-Division Electrostatics diagnostic* (CUE, Chasteen, Pepper, Caballero, Pollock & Perkins, 2012).
- Quantum mechanics: *Quantum Mechanics Conceptual Survey* (QMCS, McKagan, Perkins & Wieman, 2010).

A comprehensive current overview of these concept inventories can be found in (Madsen, McKagan & Sayre, 2017).

Several surveys have also been designed for assessing student attitudes towards science, approaches to learning physics and epistemological beliefs. These include:

- The *Maryland Physics Expectations survey* (MPEX, Redish, Saul & Steinberg, 1998), which probes for general beliefs about physics and learning physics.

- The *Views About Sciences Survey* (VASS, Halloun, 1997).
- The *Epistemological Beliefs Assessment for Physical Science* (EBAPS, Elby, 2001), designed for high school physics.
- The *Colorado Learning Attitudes about Science Survey* (CLASS, Adams et al., 2006), which builds on the other surveys and includes a broader scope of issues.
- *Colorado Learning Attitudes about Science Survey for experimental physics* (E-CLASS, Wilcox & Lewandowski, 2016b), which includes topics about the experimental basis of physics knowledge.

2.4 Developments in contemporary PER

As described in previous sections, PER is a mature field that has been able to contribute greatly to the understanding of physics learning and the improvement of physics teaching. It has done this through a tight involvement with physics and physics teaching, and this has enabled studies that use a deep understanding of physics together with a thorough experience of physics education to provide deeper insights in what matters for the learning of physics. Even though the main part of the research still being done today can be classified as "exploring students' understanding of physics concepts", a continuous development of new research areas, theories and methods has expanded the horizon of studies in PER. This section will describe the development of theories, methodologies, and research areas at the forefront of PER research.

2.4.1 Use of theory

Most early studies in PER were empirical and exploratory and did not use or develop any extensive theoretical frameworks. McDermott and Redish (1999, p. 765) argue that this is perfectly acceptable for a new research field but that a theoretical framework nevertheless can be useful. Several theoretical frameworks have since been used and developed in PER. Karen Cummings, in a report describing the development of PER, argues that early PER research was "born of a Piagetian framework both in regard to ideas of concept formation and use of clinical interviews to determine them" (Cummings, 2011, p. 9) and lists several other frameworks that have also been used: Vygotskian social constructivism (Smith, diSessa & Roschelle, 1993), a theory of "cognitive apprenticeship" in expert-novice transition discussions, and different versions of a "knowledge in pieces" frameworks, from diSessa's p-prims (1993) to the resources framework elaborated by Hammer, Elby, Redish and others (Hammer & Elby, 2003; Hammer et al., 2005; Redish, 2003).

Several authors state that the theoretical frameworks developed in PER do not come close to being as well-developed and having the same predictive

power as physical theories, and warn that this may never be the case, even though they do not exclude that possibility (Heron & Meltzer, 2005, p. 391; McDermott & Redish, 1999, p. 765). To me, this is rather surprising, given the social nature of education. Perhaps the claim by Heron and Meltzer that some PER researchers aim at "elucidating a few fundamental principles from which broad explanatory if not predictive power can be derived" (2005, p. 391) can be taken as evidence that PER is strongly influenced by a physics mindset, where there is hope for a unification of science.

In the discussions about theory, some researchers argue more strongly for the necessity of using a theoretical framework. Edward Redish is one of the most influential proponents of this view, and his advocacy of the resources framework took its start in the beginning of the 2000s when he delivered the paper "A Theoretical Framework for Physics Education Research" and has continued ever since (Redish, 2003, 2014). Similarly, Cedric Linder has been an equally strong proponent for theory and this has influenced the theoretical focus of the PER group in Uppsala, where development of new theories and approaches has been the focus for most work. Examples here are development of phenomenography (Adawi, 2002), epistemological mindsets (Domert, 2006), qualitative discourse investigations of student attrition (Friis Johannsen, 2007), gender perspectives (Danielsson, 2009), linguistic perspectives on disciplinary discourse (Airey, 2009), disciplinary discernment (Eriksson, 2014), social semiotics (Fredlund, 2015), and complexity theory (Forsman, 2015). This theoretical development aside, some PER researchers maintain the view that "empirical studies that are not necessarily closely identified with a specific theoretical framework will continue to lead to significant advances in instruction" (Heron & Meltzer, 2005, p. 391).

2.4.2 Methodology: research paradigms in PER

PER inherits some of its methodological views from physics itself, but has from the beginning used many qualitative inquiry methods, including interviews and classroom observations. Still, comprehensive and statistically significant evidence gathered through large surveys is often seen as the most legitimate source for claims about physics learning. However, the development of qualitative research in PER is one of the areas that my research contributes to, and I believe that an increased attention to the basis of knowledge claims about the social reality of education achieved through qualitative (or quantitative) methods is important for the continued development of PER.

Even though methodological issues have been highlighted for example in the theme of the 2016 PER conference (PERC) where Paper III was presented, the discussion about methodological paradigms in PER is not very extensive. However, Robertson, Scherr and McKagan (2018), in a currently unpublished preprint, argue that there are two broad paradigms in PER, and that these do

not necessarily have a one-to-one correspondence with specific (quantitative or qualitative) methods but are rather defined by their ontological and epistemological premises. The paradigms they outline are: recurrence-oriented and case-oriented research (which may however be mixed). They argue that researchers from the different paradigms may need to engage in dialogue in order to understand each other. In a companion paper, the authors aim to provide material for this dialogue as an explanation of the basis for and practices of case-oriented (mostly qualitative) PER, for "researchers who primarily identify with the recurrence-oriented PER paradigm" (Robertson, McKagan & Scherr, 2015, p. 1).

In the few other texts discussing qualitative research in PER, I find that "qualitative" in PER entails a rather specific view of the social world, one that in the terminology of Lincoln, Lynham and Guba (2011) mostly seems to match a post-positivist paradigm of qualitative research. In a chapter outlining the development of qualitative research in general, Lincoln et al. (2011) argue that qualitative research can characterized as drawing from five paradigms: positivist, post-positivist, critical theory, constructivism, and participatory research. They describe how a great deal of critique of the realist views of traditional positivist and post-positivist paradigms has led to the more elaborate views of social reality defended in critical theory and constructivism (Lincoln et al., 2011).

In evaluating PER literature on qualitative methods, I find limited discussion about these issues, and no mention of the "crisis of representation" that has led researchers in other fields of social science to question the overly realist assumptions of traditional views. Qualitative methods are seen as a road to getting closer to an unproblematized social reality. In a report from a seminar at PERC in 2002, Sandifer and Johnson discuss problems with the validity of qualitative research as possible "inaccurate perceptions" of the student or researcher. They also describe "influencing the subject" as a significant risk of interviews. This understanding of qualitative research seems to adhere clearly to a post-positivist view, where we can approach knowing the real processes of social interaction (but not prove that we know them) if we are sufficiently careful. In a similar vein, Otero and Harlow (2009), in a manual for doing qualitative PER research, discuss the validity and reliability of qualitative research as requiring "triangulation" and "thick description" to get an "accurate view of the participants' reality" (2009, pp. 59–60). Robertson et al. (2018) problematize this view by emphasizing the subjective construction of reality, and the various roles that case-oriented research accounts can play.

What seems absent from the majority of methodological discussions in PER is a critical perspective on meaning-making, power, and knowledge that has been taken in educational research and other social science relating to the crises in "representation" and "authority" (Lincoln et al., 2011, p. 124). Taylor (2014), in outlining the paradigms of qualitative research in science education, argues that when these issues are ignored, qualitative research is seen as easily

reconciled with traditional quantitative research, which "tends to result in research designs governed by the epistemology of the post-positivist paradigm" (Taylor, 2014, pp. 40–41). The idea of triangulation, "an automatic 'weapon of choice' to optimize the validity and reliability of many contemporary mixed-methods research designs" (p. 45), also risks building on this post-positivist reasoning. Contrary to this, the epistemological starting-points of contemporary qualitative researchers working in the paradigms which Taylor (2014) lists as interpretive, critical, and postmodern, rather serve to take into full consideration the epistemological crises of representation and authority, and develop research according to this.

I believe that PER would benefit from taking part in the theoretical and methodological developments that have come with interpretive, critical and postmodern paradigms, similar to many researchers in the latest wave of science education. This is something my project aims at doing. Maybe PER should take heed of the claim of Robertson et al. that "our understanding of PER as a discipline can be informed by our understanding of research in the social sciences" (2018, p. 17; see also van Aalst, 2000). Doing so might enable a wider discussion of which epistemology and methodology, be it quantitative or qualitative, is most applicable when studying various aspects of physics education.

2.4.3 Cognition and context

The majority of PER has approached physics learning as something that is expected to happen for, or within the individual student, that is, "cognitive learning". In light of the discussion in the previous sections, it is not surprising that this has been the primary focus. The major concern of any physics instructor is to help students understand physics better, and research then starts with the questions: what, how and why do they (not) understand? While this aspect of learning is certainly vital, it usually does not cover the complete picture of physics education for students. For example, the popular sociocultural framework of situated learning points to how learning also often needs to be considered a question of gaining legitimacy in communities of practice, that is, a question of *participation* (Lave & Wenger, 1991). This means that the sociocultural *context* of students' learning environments needs to be considered to a much greater extent. In studying human beings, we cannot really ignore the social aspects of education and only focus on the cognitive.

One example of an area where a sociocultural perspective has proven valuable for more nuanced understandings is attitudes research. A sociocultural critique of earlier common psychological notions of students "holding" attitudes points to how attitudes are seldom particularly stable and can more helpfully be seen as negotiated in relation to social identities (Tytler, 2014). In

light of this, it is worth thinking about the interpretation of attitude surveys etc.

However, the central area where a more context-sensitive and sociocultural perspective has been starting to be employed in PER is in research on issues of equity and diversity. This research perspective questions whether a concern with how students learn physics is the only aspect that the physics community should care about. Instead, perhaps significant reform and research efforts should be put into the questions of if, how and why some students are more likely to choose and succeed in physics, and whether these processes can be seen as fair. After all, if physics education research wants to understand more than what happens "inside the head" of students who are already in physics, and paint a fuller picture of physics studies, more extensive research approaches that attend to the whole sociocultural context of physics studies are needed. The next section will describe research that focuses on issues of diversity, equity, gender and identity in physics education, by employing more or less sociocultural research frameworks.

2.5 Diversity, equity, gender, and identity in PER

Traditionally, both science education research and PER have paid limited attention to sociocultural issues with the major concern being students' conceptual understanding (Chang, Chang & Tseng, 2010; Traxler et al., 2016). However, a growing focus on these issues has come with societal concerns over the lack of diversity in STEM education (European Commission, 2004; President's Council of Advisors on Science and Technology, 2012). While policy reports from governments often point to the underrepresentation of women and minorities in science as a problem of a too weak STEM workforce, this is also a question of social justice: if certain students, perhaps due to a complex interaction of large societal structures and local discriminatory practices, are excluded from science, the system is unjust. However, while the problem of underrepresentation of women and minority students has at times been framed as a problem with recruitment and retention, there exist few easy fixes in these fields (Tinto, 2006). Over the last twenty years, research on student retention has increasingly pointed to the complex interactions between students and the university system as the major concern (Seymour & Hewitt, 1997; Tinto, 2006).

Looking at the numbers for science and physics, we can see that while natural sciences in general have gender parity at undergraduate level (OECD, 2017b, p. 26), women are still underrepresented as researchers (UNESCO, 2015, chapter 3), and in physics the proportion of women is still around 20-30 percent in many countries (American Physical Society, 2018; OECD, 2017a; Universitetskanslerämbetet, 2016). The causes for this can often be attributed to factors outside of higher education. Historically, women were excluded

from professions like science. Today however, some fields, like physics and engineering, seem to still carry more masculine connotations while other fields, such as life science, are seen as more compatible with femininity. These associations are widely seen as influencing the interests and study choices of young people (Schreiner, 2006; Sikora & Pokropek, 2012).

A feminist critique of science places some of the blame on science itself, pointing to how androcentric values have permeated science from the start (Lloyd, 1984; Merchant, 1980) and still lead to both bias and a culture hostile to women (Harding, 1986; Keller, 1985; Schiebinger, 1999). While some of these claims are primarily based on philosophical and historical investigations, detailed anthropological studies have also pointed to the masculine features of scientific culture. Sharon Traweek, in a now classic study of high-energy physicists, described how physics was considered a neutral science, not having to do with people, and that physics thus could be considered a "culture of no culture" (Traweek, 1988, p. 162). Nevertheless, she could point to how masculine norms permeated expected behaviours, careers and symbolism in physics, both in the US and Japan. A more recent study, comparing physics culture across multiple European countries, is the UPGEM project. The results from this project show that while there are significant variations across national contexts, a masculine ideal for physicists can be found in the widely spread "Hercules culture" of doing physics. The ideal physicist in this culture is a "Hercules" figure characterized by competitiveness, self-confidence, and a passion for physics precluding most other concerns. This position may be attainable for women, but when the culture of physics departments encourage these attitudes it mostly has negative effects for women (Hasse & Trentemøller, 2008).

In the light of these concerns and results, the attention paid to issues of gender and equity is growing in the PER community. In the next few sections, I will characterize this research and outline some of the things that I believe are still missing and that my research aims to provide.

2.5.1 PER focusing on gender, equity and identity

PER has up until recently focused little on issues of gender and equity. Heron and Meltzer, in their characterization of PER, exclusively "highlight those directions that address intellectual issues that are specific, but not necessarily unique, to the subject matter and reasoning patterns of physics" and therefore "omit important work on investigating gender-equity issues, for example" (Heron & Meltzer, 2005, p. 390). That is, PER is characterized as only concerned with the "purely" cognitive aspects of learning physics. In my view, it is difficult to ultimately separate the subject matter and reasoning patterns of physics from the sociocultural aspects in analysing student learning. This can be characterized as taking a "participation" perspective on physics education,

putting students' full experiences first instead of focusing on physics content or the priorities of the discipline.

When gender and equity issues are attended to in PER, it has generally been in a somewhat limited way. Docktor and Mestre, in their commissioned paper for the National Research Council (which was later published as Docktor & Mestre, 2014), argue for the importance of social issues in a way that is quite symptomatic:

> Another general area that needs attention is the disaggregation of data in terms of underrepresented minorities or academic majors. Most research studies do not consider multiple, diverse student populations in their design or in reporting results.
>
> The small fraction of women and minorities participating in physics is cause for additional attention to the issues facing these groups, including additional research to explain observed performance differences on concept inventories. (Docktor & Mestre, 2011, pp. 144–145)

Here, what is envisioned as needed is "disaggregation of data" and "research to explain performance differences", something that limits explorations of these issues to mostly quantitative investigations of differences.

However, in recent years, increasing attention has been paid to concerns about equity, recruitment, retention and other sociocultural issues in PER, and with this upsurge of interest, various theoretical and methodological approaches have been tried. One way of characterizing this development, covering at least the PER scene in the US, is to look at contributions to the annual PER conference (PERC). These conferences have been organized since the late nineties and the short, peer-reviewed, contributions to the proceedings (available from 2001) generally represent ongoing projects that are later published in journals. A search for the terms "gender", "equity", and "identity" throughout the titles and abstracts of all proceeding contributions from 2001 to 2017 shows a general trend of increasing interest in these issues, with a marked peak for the 2012 conference, the theme of which was "Cultural perspectives on learners' performance and identity in physics" (see Figure 2.1). I will be discussing the development of the contributions to PERC further below.

2.5.2 A characterization of topics

In reviewing PER work studying sociocultural issues, I draw from the earlier reviews by Danielsson (2010), and Traxler et al. (2016). However, while they focus on research about gender, and even though the works we treat overlap, I will extend the discussion to include the question of how identity has been used in PER. Danielsson carried out a literature search in the main physics education journals as well as some science education journals for search terms such as "gender", "girl", "woman", and "gender AND physics" (depending on

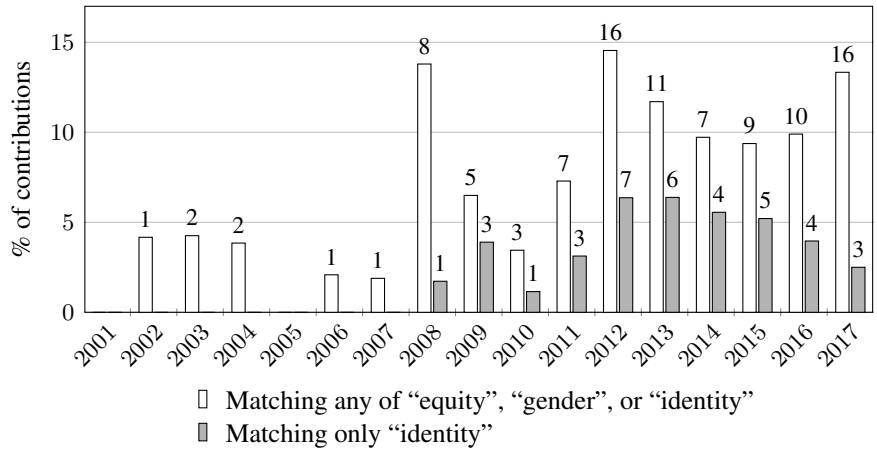

Figure 2.1. The percentage of titles or abstracts mentioning “equity”, “gender”, or “identity”, or only “identity” in the contributions to the PERC proceedings. The number of found contributions is printed on top of the bars. The total number of contributions to the proceedings are not very large and range from 24 (in 2002) to 120 (in 2017).

journal) and found a few ways in which gender issues were discussed in PER, based on the 57 papers from the search that were deemed relevant. The findings of the similar overview made by Traxler et al. (2016), some years later, largely confirm what Danielsson found. To complement these reviews I have carried out a literature search in three central PER journals: *American Journal of Physics* (*AJP*), *European Journal of Physics* (*EJP*), and *Physical Review Physics Education Research* (*PRPER*). This certainly misses some relevant research published in other outlets, but nevertheless gives a fairly accurate picture of how these issues are discussed in the mainstream of PER, centred on the US PER tradition. I searched for the terms “gender”, “equity”, and “identity” in such an inclusive way as possible (for all dates until March 2018, and in titles, abstracts and full text) in the three journals, intending to capture research concerned with social issues but not only focusing on gender. This search yielded hundreds of results (mostly because “identity” is a word used in many physics contexts), but a screening of titles and abstracts reduced these to a total of 96 papers judged relevant, i.e. discussing issues of gender, equity or social identity to some extent apart from just plainly reporting statistical differences between men and women found in a study primarily focused on other issues. This material spans from discussions in *AJP* in the 80s of “women in physics”, with refutations of ideas of biologically based cognitive differences (Bleier & Engle, 1987), to detailed analyses of discrimination and gendered identity constructions (Barthelemy, McCormick & Henderson, 2016; Gonsalves, Danielsson & Pettersson, 2016; Rosa & Mensah, 2016). Publication has increased in recent years, with a significant spike in 2016 mostly due to the publication of a focused collection on gender in *PRPER* (which included

Paper I). However, my categorization of these publications largely coincides with what Danielsson and Traxler et al. found.

Both Danielsson and Traxler et al. list the primary way of researching gender in PER as "Comparison of man and woman students" (Danielsson, 2010, p. 70), something which is generally done by analysing data from the standardized measures of conceptual knowledge, or perhaps attitudes and interest, commonly used for evaluating teaching in PER (see Section 2.3.5). Several studies specifically discuss the "gender gaps" in performance on concept inventories, what factors seem to influence them, and how they could be overcome (Bates et al., 2013; Henderson, Stewart, Stewart, Michaluk & Traxler, 2017; Kost-Smith, Pollock & Finkelstein, 2010; Kost, Pollock & Finkelstein, 2009; Kreutzer & Boudreaux, 2012; Lorenzo, Crouch & Mazur, 2006; Madsen et al., 2013; Pollock, Finkelstein & Kost, 2007). This is in general done through quantitative methods, and recent years have seen explorations of more factors that might influence the gap. A paper by Madsen et al. (2013) analyses 26 papers about gender gaps on mechanics concept inventories and the possible factors put forward as involved in these papers. They conclude that no single factor can account for the total gap, which is "most likely due to the combination of many small factors" (Madsen et al., 2013, p. 1), something which in another paper has been referred to as a "smog of bias" (Kost-Smith et al., 2010). The general procedure of this vein of research can be characterized as disaggregating quantitative data, and finding "factors" which contribute to gender gaps or efforts that can reduce them. However, as Traxler et al. mention when discussing Madsen et al. (2013), this rarely involves taking a critical view of the culture of physics and treating it "as a factor that might contribute to or reinforce the reported gender gaps" (Traxler et al., 2016, p.5). In the analyses of gender gaps, revised and more gender equal variants of the Force Concept Inventory have been proposed (McCullough, 2004; McCullough, Meltzer, Franklin & Cummings, 2001) and a recent analysis recommends excluding certain items found to be gender-discriminating (Traxler et al., 2018).

Another large area of investigation is "classroom practices" (Danielsson, 2010, p. 71) or "effects of reformed pedagogy" (Traxler et al., 2016, p. 5), where results from the many teaching methods and curricula developed by PER researchers are analysed to "compare how man and woman students respond to a certain form of teaching" but also in some instances "discuss how to make the physics classroom more 'girl friendly'" (Danielsson, 2010, p. 72). Some of the recent studies in this field explore how modern teaching methods possibly are more inclusive than traditional teaching (Brewe et al., 2010; Chasteen, Pollock, Pepper & Perkins, 2012; Gunter, Spiczak & Madsen, 2010; Karim, Maries & Singh, 2018; Van Ness & Widenhorn, 2012). A specific topic in this vein of research is how collaboration or group work may be gendered in the often interactive curricula implemented in PER research (Harlow, Harrison & Meyertholen, 2016; Pawlak, Irving & Caballero, 2018; see also Due,

2012). However, quantitatively measuring whether a certain curriculum supports greater equity is intricate and replications of some of the results have proven difficult (see Madsen et al., 2013, and Traxler et al., 2016 for some discussion of this). A few of the problems in this research concern the choice of statistical measures (effect size can be argued to be better than focusing on statistical significance in normalized gains) and the model of equity used (Rodriguez, Brewe, Sawtelle & Kramer, 2012).

Focusing less on performance and more on contextual issues, many studies also investigate interest, attitudes and retention, also here often by comparing men and women, or students with different backgrounds. These studies often use the instruments developed to measure student attitudes, like CLASS (Traxler & Brewe, 2015) or E-CLASS (Wilcox & Lewandowski, 2016a). A gender gap that has often been reported throughout STEM education is in self-efficacy, the belief in one's abilities in a subject (Eddy & Brownell, 2016). This has also been explored in physics where one study found that interactive engagement teaching may disadvantage women (Nissen & Shemwell, 2016). Taking departure in concerns over the low proportion of students choosing STEM, and physics in particular, many studies investigate students' interest in science and physics (Crouch, Wisittanawat, Cai & Renninger, 2018; Dare & Roehrig, 2016; Levrini et al., 2017; Sax, Lehman, Barthelemy & Lim, 2016). In general, physics is a subject choice driven by interest (Bøe & Henriksen, 2013; Levrini et al., 2017), and many of the large quantitative studies have pointed to how reported interest differs between men and women, if not always in extent, sometimes in the direction of the interest (Adams et al., 2006; Bøe & Henriksen, 2013). Some of the findings indicate that women or girls choosing physics often differ from other women on several items, for example extroversion (girls interested in physics score lower on extroversy measures, Mujtaba & Reiss, 2013) or social activism (women in physics are not as motivated by social activism as in other college subjects, Sax et al., 2016). By analysing a large survey dataset about students' interest and study choice, Hazari, Potvin et al. (2013) found that having discussed women's underrepresentation was a factor that predicted larger interest in studying physics. These findings generally do not permit a much deeper analysis of the mechanisms behind the results, although qualitative follow-ups like Lock and Hazari (2016) may be a way of explicating the issues.

Some recent developments in these fields use network analysis (Brewe, Kramer & Sawtelle, 2012; Bruun & Brewe, 2013; Dou et al., 2016; Zwolak, Dou, Williams & Brewe, 2017) and an operationalization of the identity concept (Hazari, Cass & Beattie, 2015; Hazari, Sadler & Sonnert, 2013; Hazari, Sonnert, Sadler & Shanahan, 2010) to investigate students' study choice, attitudes, interest and persistence. I will discuss the topic of identity and how I use it in relation to other research below.

2.5.3 A lack of critical perspectives?

Both Danielsson (2010) and Traxler et al. (2016) highlight a lack of critical perspectives on gender, science and physics culture in the studies they review, and I can conclude that the pattern is similar for the articles I found in my search. The most common approach is still to compare men and women, which is of course a basis for equity measures, but is probably not enough to get to the root of problems. In particular, Traxler et al. (2016) call for studies that include more complex understandings of gender and that use more complex quantitative or in-depth qualitative analyses. I agree with this critique. First, the term gender generally refers to "social sex", but when it is seen as a static category that divides people into two groups which can be compared, there is a risk of reifying gender, making it the new "politically correct" name for "biological sex" (for a discussion of the "rise of gender and decline of sex" in academic usage, see Haig, 2004). This is apparent in phrases like: "The two genders make different use of being allowed multiple tries to solve online homework problems: male students frequently attempt to immediately solve the problem, while female students are more likely to first interact with peers and teaching assistants before entering answers." (Kortemeyer, 2009, p. 1) But treating gender as static also runs the risk of seeing it as "the" culprit of gender gaps. In statistical language, gender becomes a "factor" that possibly influences students' results. We have: "Gender as a factor of science achievement" (Cataloglu, 2007, p. 770). Traxler et al. (2016) discuss this as a "binary gender deficit model", where "female students are presented as lacking some combination of science-like traits (math preparation, or self-confidence)" and "the implied solution is to help women be more like men" (pp. 9-10).

This is in contrast to how gender is conceptualized in for example gender studies, but also in other more critical examinations of gender and education such as those published in journals like *Gender and Education* or *Cultural Studies of Science Education*. Here gender is most often viewed as dynamic, a part of an ever-changing social identity, and something that is "done" or "performatively constituted" rather than something one has (Butler, 1990/1999; West & Zimmerman, 1987, see also Chapter 3 below).

It must also be noted that the PER-centred overview given here does not cover many relevant works in the Scandinavian education research tradition, where much critical attention has been given to gender and identity issues both in physics and science university education in general. Example of topics here are signals given in recruitment communication (Andrée & Hansson, 2014), identity in student associations (Widding, 2006), positioning in problem solving (Berge, 2017; Berge & Danielsson, 2013; Due, 2012), masculinity (Ottemo, 2015), study choice and identity (Holmegaard, Madsen & Ulriksen, 2014; Madsen, Holmegaard & Ulriksen, 2015), and the in-depth anthropological investigation of physics education done by Cathrine Hasse (2002, 2008).

2.5.4 A look at the most recent work

While the majority of studies concerned with equity and diversity issues in PER seem to be at risk of propagating a deficit model of gender, some newer research draws from other frameworks and traditions to apply critical perspectives on gender, physics, and physics education.

One source for what can be considered state of the art research with gender perspectives in PER is the *PRPER* focused collection on gender where Traxler et al. (2016) and Paper I was published. The call for papers for this collection explicitly invited studies that "compare men to women in physics", but also "[s]tudies of gender identity in physics" in the list of relevant topics, and welcomed "both qualitative and quantitative work " (Henderson, 2014). The majority (8) of the empirical papers in the collection are however still based on quantitative comparisons of men and women.[1] Some of the few qualitative studies reported in the collection draw from other, critical research traditions like critical race theory (Rosa & Mensah, 2016), gender performativity (Gonsalves et al., 2016), and theories of discrimination and microaggressions in masculine cultures (Barthelemy et al., 2016).

An increased attention to equity and diversity can be seen not only in published journal articles but also in the contributions to PERC, as discussed earlier in Section 2.5.1. While there have always been a few contributions discussing gender differences in performance and other measures, the last few years has seen an increase in the focus on equity issues and activities to overcome them, as well as an interest in researching identity (see Figure 2.1), paralleling the research published in journal articles. Attending to this concern about equity, several practical approaches have been developed: activities engaging students in discussions about equity (Daane & Sawtelle, 2016; Decker & Daane, 2018, these are similar to what was organized by Staffan Andersson in the introduction for physics students at Uppsala University), focused departmental work to improve representation (Rainey, Corbo, Reinholz & Betterton, 2016), and investigations of the reasoning about inequities among physics faculty members (Turpen, Little & Sawtelle, 2018). In addition to this, frameworks discussing these issues in terms of identity have become more prevalent in the last years. Some (e.g. Lock, Castillo, Hazari & Potvin, 2015; Monsalve, Hazari, McPadden, Sonnert & Sadler, 2016) draw from the statistical modelling approach of Hazari et al. (2010) while others apply more qualitative, interpretative and sometimes critical research approaches (Hyater-Adams, Fracchiolla, Finkelstein & Hinko, 2016; Hyater-Adams, Williams, Fracchiolla, Finkelstein & Hinko, 2018; Ko, Kachchaf, Ong & Hodari, 2013; Monsalve et al., 2016; Richards, Conlin, Gupta & Elby, 2013; Rodriguez & Potvin, 2018).

[1] Dare and Roehrig, 2016; Day, Stang, Holmes, Kumar and Bonn, 2016; Ivie, White and Chu, 2016; Koul, Lerdpornkulrat and Poondej, 2016; Nissen and Shemwell, 2016; Potvin and Hazari, 2016; Rodriguez, Potvin and Kramer, 2016; Wilson, Low, Verdon and Verdon, 2016.

Despite these newer contributions, the majority of work published to date in the PER journals deals with equity and gender in terms of "gaps". In this tradition, gender and other social relations are seldom theorized, and with this follows an underdeveloped approach to social change that may pay little attention to the power issues embedded in social inequities and instead work on a premise of making everything better for everyone. Some of the more theoretical contributions to the *PRPER* focused collection draw from social psychology, where the quantitative measures of attributes like interest or self-efficacy are connected to potential factors that may influence these measures in multi-variate analyses (Eddy & Brownell, 2016; Kelly, 2016; Lewis, Stout, Pollock, Finkelstein & Ito, 2016). In arguing for this theoretical orientation, Eddy and Brownell "urge discipline-based education researchers to move beyond the natural sciences to begin conversations and collaborations with social psychologists and sociologists to better study some of these underlying mechanisms" (2016, p. 2). However, sociological perspectives seem to be largely missing from most PER research, where a cognitive perspective and a focus on individuals rather than social structures still prevails and a social psychological perspective may be the only next logical step in widening perspectives. Some of the common "input factors" of gender differences considered in the literature I have discussed until now are "stereotypes", "gendered socialisation" and "role models" (Eddy & Brownell, 2016; Kelly, 2016; Lewis et al., 2016). Eddy and Brownell (2016) develop a model for STEM career interest based on these considerations (see Figure 2.2). The major problem with discussing inequities in this way is that it does not allow for a detailed discussion of power, but instead again reproduces a picture of the individual (or statistical) student as more or less influenced by appropriate (or unjust) factors to a desirable (or deficient) attitude or affect. This may fail to take into account power differences and how students experience and negotiate their education in practice. In the model proposed by Eddy and Brownell (2016), gender and race are pictured as two of many "ultimate causes" of students' psychological relations to STEM and observable inequities. A critical analysis informed by sociology or gender research would however not posit individuals' gender as the cause for inequity, but rather as an axis along which inequity is structured. To me, it seems dishonest to tell students that their (inappropriate) gender or race is a cause of the inequities in STEM education as is implied in Figure 2.2. We are then again back with a form of the deficit model criticized by Traxler et al. (2016).

In my view, issues of equity and diversity need to be addressed with theoretical and methodological tools that allow attention to be paid to both the social structures of education systems and the individual agency of students to negotiate these structures, without losing sight of power.

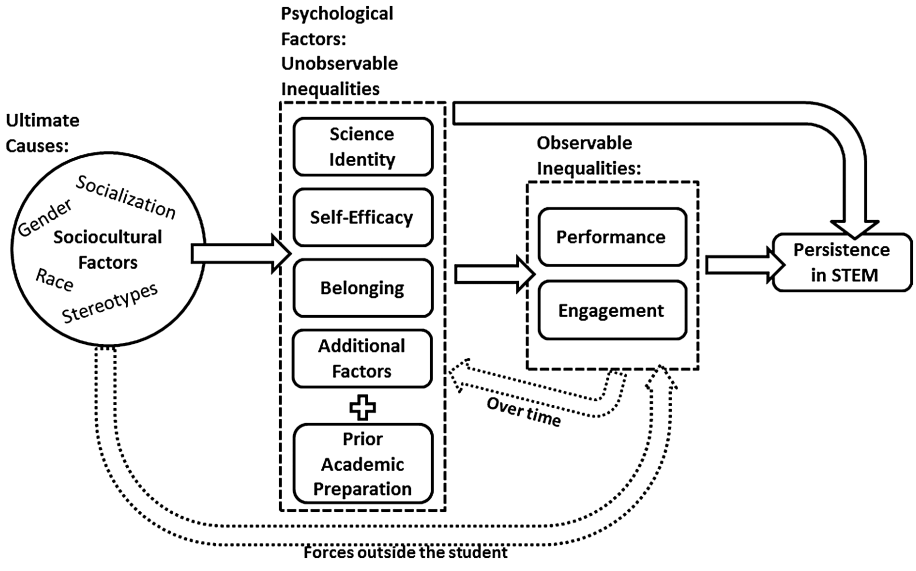

Figure 2.2. Diagram reproduced from Eddy and Brownell (2016, p. 11). Original caption: "Model describing how gender gaps in affective and observational measures can impact persistence in STEM and the underlying sociocultural factors influencing all of them. Modified from Wang and Degol's [87] model for understanding career choice." (reproduced under CC BY 4.0 license).

2.5.5 Critical perspectives on gender and identity

Having described the majority of research concerned with issues of social equity published in the major PER journals, it is worth taking a step back to evaluate this research in terms of its critical potential.

Hussénius, Andersson, Gullberg and Scantlebury (2013), in an examination of the attention paid to gender in science education, outline three different approaches of research with a gender perspective: research addressing gender, gender research, and feminist research. Whereas "Research addressing gender" is characterized as any research using "sex or gender as analytical categories", the two latter categories of research use "gender theoretical frameworks" and/or "gender perspectives to analyse power" (2013, p. 302). Additionally, "Feminist research" has the stated aim of changing power imbalances, i.e. subscribing to a critical research paradigm (Lincoln et al., 2011; Taylor, 2014; Treagust et al., 2014). Through literature searches, the authors point out that very few studies in science education consider gender at all, and that those doing so are almost exclusively of the "addressing gender" kind. As I have already discussed above, this is also the case in PER.

One explanation for this lack of critical perspectives, in PER and science education, can be that a post-positivist paradigm is still dominant in both fields. The philosopher of science Sandra Harding, in discussing science and gender 30 years ago, claimed that:

> [R]esearch programs where remnants of empiricist, positivist philosophies of social science hold sway have been systematically inhospitable to gender as a theoretical category. At best they have been willing to add gender as a variable to be analyzed in their subject matter—as a property of individuals and their behaviors rather than also of social structures and conceptual systems. (Harding, 1986, pp. 33–34)

Perhaps this still holds true for the default approach to treating gender in physics. Taking issue with the contemporary feminist discussions of science, Harding describes five more or less radical research programmes, from "equity studies", which ask why there are so few women in science, to elaborations of feminist epistemologies, which take the critique to the very root of knowledge production (Harding, 1986, pp. 21–24).

With this background, we can note how the "gender as a variable"-paradigm still dominates much of the research treating gender issues in PER. From the more atheoretical reporting of gender gaps on different measures, to the more elaborate social psychological investigations. Once again taking Eddy and Brownell (2016) as an example, the authors are certainly aware of the complexity of gender and note that "gender identity exists on a spectrum and that more than two genders exist in the human experience." (Eddy & Brownell, 2016, p. 1) Nevertheless, in the framework they formulate, gender is simply a binary factor. This problem also plagues the "physics identity" construct, as defined by Hazari et al. (2010). Even though the results gained by regression analysis of the big data sets of multiple indicators of interest, preparation etc. used by Hazari et al. (2010) are useful and valuable, I doubt the value of fixing physics identity as a statistical combination of measured performance, competence, recognition and interest. In my view, a more dynamic notion of identity can allow for more in-depth understanding of students' life-worlds. One example of how identity and gender can be studied in a more complex way is in explorations of how students simultaneously *do* physics and gender, that is, participate in the social construction of both physics and gender through their talk and actions (Danielsson, 2009).

A critical discussion of how "identity" is used and conceptualized in PER and an argument for why using more discursive frameworks may be valuable is the main contribution of Paper III. In the paper, I draw on a critique of identity studies in science education by Marie-Claire Shanahan, who claims that many studies use identity in a way that foregrounds agency and fails to critically assess the structures that limit agency in identity constructions. In particular, one common way of using the communities of practice-framework (Lave & Wenger, 1991; Wenger, 1998) by focusing on the legitimate peripheral participation of individuals "tends to take the norms as given and attends to how individuals navigate those norms" (Shanahan, 2009, p. 57).

To the picture developed in Paper III another characterization of identity concepts can be added: the dimension of possession and negotiation. Lilian L.

Pozzer and Phoebe A. Jackson (2015), in reviewing uses of identity in science education, point to how identity is most often perceived as either something which a person possesses or as something negotiated in interaction, but that many authors, despite declaring that they use one perspective, often use an inconsistent terminology. In characterizing the possession perspective they note:

> Often such papers presented identity categories, such as science identity or ethnic identity, and discussed how participants brought these identities into different contexts, and how these identities influenced how the participants engaged with their social world. Other key indicators of a possession perspective on identity included the use of terms such as identity development and identity formation, which portrayed identity as a personal characteristic that is shaped over time in a cumulative process rather than being re/constructed in interaction. (Pozzer & Jackson, 2015, p. 223)

They further note that almost all papers adopting negotiation perspectives focused on issues of equity, something which I find unsurprising and that "can be explained by the inherent socio-critical perspective that is foundational to a view of identity as negotiated in interactions" (Pozzer & Jackson, 2015, p. 224). Using a possession or a negotiation perspective can imply different perspectives on agency and structure. A possession and development perspective means a focus on adaption to the structure or norms of a community, while a negotiation perspective may allow for more explorations of renegotiations of norms. So, taking the critiques of Shanahan and Pozzer and Jackson together, the problem with perspectives centred too much on agency and possession is that structure and power are not attended to as something which can be changed, but are rather taken for granted. The imagined peripherally participating student navigates the given norms of the community to create an appropriate identity, while the student possessing a "core" or other identities has been "given" this identity by social (or natural) and unquestioned structures. In Chapter 3, I will discuss more fully how a performative poststructuralist account of identity is a way of navigating the structure–agency dialectic that can attend both to disciplinary power and individuals' possibilities to act within restrictive systems.

In PER research using identity perspectives, identity is often conceptualized as something a student possesses and develops. For example, Irving and Sayre (2015) discuss "becoming a physicist" as acquiring a physics identity and being recognized by the physicist community. While the authors declare their communities of practice-inspired approach as using an "activity" rather than "property" ontology of identity, they also focus on identity development, and as I read their results, this perspective still means labelling students as possessing certain (more or less developed) identities. In general, a development perspective seems to be common among the approaches to identity studies in PER (Close, Conn & Close, 2016; Gretton, Bridges & Fraser, 2017; Lock &

Hazari, 2016; Rodriguez, Goertzen, Brewe & Kramer, 2015). I believe that this view is valuable when asking questions about student retention and attrition, but there is a risk that, if this is not combined with a critical perspective of science, the research will align itself with an instrumental (from the point of institutions) view of students. If "becoming a part of some scientific community" is taken for granted as an evident goal, we risk missing the perspectives of the students who actually resist a "physics identity" and do not want to be part of the physics community as it is presently formed, and we fail to critique the possibly undemocratic tendencies of that community. While becoming a member of the relevant disciplinary community is a central part of education, the task for researchers and educational reform cannot only be to help students gain a "suitable" identity. The "acquiring a science identity"-perspective is thus not critical enough in the frameworks of Harding and Hussénius et al., since it fails in analysing power in any significant way. Perhaps what we are seeing here is again the "deep grounding in the discipline's priorities, worldview, knowledge, and practices" (National Research Council, 2012, p. 9) of Discipline-Based Education Research.

There are, however, a few studies that do use the identity concept to develop a more fully critical analysis of gender and other structures in physics education. These studies can be classified as "feminist research", and serve as an inspiration for my project. One approach to how the communities of practice-framework can be used in nuanced ways to study gender and power (it has been criticized for leaving these things out, Salminen-Karlsson, 2006) is to combine it with discourse analysis, as done by Danielsson (2009). In a thematically related study (the findings are summarized and analysed together in Gonsalves et al., 2016) of the education of physics PhD students, Allison J. Gonsalves (2014) examines what forms of being a physicist are "recognizable" in the context of doctoral education. Using a social constructionist, poststructuralist view of gender and identity, she specifically asks what "subject positions" are available to female doctoral students in physics. Gonsalves finds that the available positions seem limited. In particular, she argues that as competence in experimental physics seems to bear strong masculine connotations, the female physicists always seem to stand out as "other". At the same time, stereotypical femininity is constructed in opposition to the purported "neutrality" of physics, and this means that a recognizable woman physicist position relies on difference both to "other women" and "ordinary physicists". The theoretical perspective employed in this study lies close to my own and I particularly find the notion of "positions as a physicist" in discourse useful. A similar focus on the constraining role of discourse for students in physics can be seen in the work of Larsson, Airey, Danielsson and Lundqvist (in press) that examines the discourses of a physics teacher education programme. Here, the authors identify four competing discourse models in the talk of physics teacher educators that can be seen to both enable and limit the identity performances that trainee physics teachers can legitimately enact. Yet another study that uses an

in-depth, qualitative and mostly sociological approach is Maria Ong's investigation of the identity negotiations of women of colour in physics education (2005). Here, a complex understanding of processes of gendering and racialization as well as their intersection is used, and a very explicit focus is put both on the agency of the informants to negotiate limiting structures and how these structures can ultimately be changed. This also highlights the importance of studying identities with a view of how different structures of power intersect, something that has been recognized in gender studies and other fields for many years and more recently been conceptualized as "intersectionality" (Crenshaw, 1991; Davis, 2008).

2.5.6 What is missing?

Increasing attention is being paid to issues of diversity, equity, gender, and identity in physics education research. However, the majority of this research works according to what has been termed a "binary gender deficit model" (Traxler et al., 2016), and more complex and critical understandings of gender, power and physics culture are called for. Physics education research has seen the beginning of studies addressing equity issues through identity frameworks, but this research may be painting incomplete pictures and miss its critical potential if too extensive a focus is put on students' development of appropriate identities. At the same time, there is research that does adopt a critical approach to both identity and physics.

In characterizing research on identity in physics, there seem to be a few different ways of viewing disciplinary (physics) identity. One of these views is to highlight how education needs to help students in developing a disciplinary identity that comes close to being a "professional" identity, i.e. making "physicists", (Irving & Sayre, 2015), or for that matter "engineers" (Allie et al., 2009). This disciplinary focus inspires research that focuses on specific contexts and courses and how these can contribute to students' development of an appropriate (expert) identity (Close et al., 2016; Gretton et al., 2017; Rodriguez et al., 2015). These approaches however risk taking a too uncritical perspective of the discipline, and what can be considered to be an expert. A slightly different view seems to be used in studies that focus on how students' "given" identities, like gender, race or class "fit" or not with a normative disciplinary identity (Ong, 2005; Rosa & Mensah, 2016). These studies may focus on how identity needs to be negotiated, and often offer a critical perspective on the exclusions of normative identities by asking questions about who the expected student is (similar to the notion of the "implied student" in Ulriksen, 2009). Yet a third view can be glimpsed in studies that focus on disciplinary, "science", identity in school. Here, the focus can be on how students negotiate an identity as a "science person" together with other expectations about gender etc. (Archer et al., 2012), but also on how science and a disciplinary

identity as an "expert" can be reconfigured, making students from disadvantaged backgrounds take ownership of science (Archer, Moote, Francis, DeWitt & Yeomans, 2016; Barton et al., 2013; Carlone, 2017). This however primarily pertains to what happens in school, and in research about university science education, both science and disciplinary identity remain largely unquestioned.

What I believe is often missing from studies using identity in PER are critical perspectives on the *construction* of disciplinary identities in physics education, and in particular how this takes place in specific moments of physics studies. To do this would be to attempt to merge the three perspectives outlined above. It would take the detailed focus of professional identity-centred studies but at the same time not take physics or "appropriate" physics identities for granted, rather trying to create openings for re-imaginations of physics identity. In approaching these issues, I believe it is especially important to keep the diversity inside physics in focus. The physics discipline is not necessarily unitary, and physics can be perceived very differently by students.

The questions that have not been asked to a large enough extent are questions about students' interactions with physics in relation to different specializations of study but also about how specific physics subjects and content can structure negotiations for students. What does it mean to take quantum mechanics? How do students' whose main subject is not physics negotiate physics culture with other identity constructions relevant to them? What is involved in being considered an appropriate physicist-to-be on a master's programme in physics? Does choice of specialization matter? In, short: how is a successful physics student formed and conceptualized, in various contexts? The aim of this thesis is to start answering questions such as these, while employing a critical, social constructionist approach to identity, gender, and equity. In doing so, I take on board the recommendations of Traxler et al. (2018) to do in-depth qualitative work, avoiding "gap frameworks" and use a feminist approach (see also Hussénius et al., 2013) where critique and change rather than a positivist notion of objectivity are foregrounded. In this process, I continue and extend the PER tradition of bringing in new theoretical frameworks and approaches to answer questions which have previously been underdeveloped.

3. Identity in discourse

As discussed in the previous chapter, there is a need for a theoretical and methodological approach to studying identity in physics that manages to navigate the structure–agency dialectic and allows a detailed look at how physics identities are *constructed* in specific learning contexts. My focus on identity constructions already implies a theoretical commitment to a social constructionist notion of identity, but this chapter will further describe the basis for the poststructuralist, discursive, notion of identity I use. The central point of this development is that identity is viewed as an attachment to subject positions created in discourse, where positions completely outside previously established discourses are unimaginable or *unintelligible*. My take on this is that these central notions are applicable to many aspects of identity, both those seen as more personal and more context specific, such as "physics identity". Before reaching that conclusion however, this chapter will cover some ground about the identity concept in general, and explain why I have been wary of using it in a too sweeping way in my writing.

3.1 What is meant by theory?

As this chapter will describe the theoretical background of my work, it is important to first establish what I mean when I say theory. In Section 2.4.1, I described how PER research from the beginning often did not use explicit theoretical frameworks, but how over time, several general frameworks for conceptualizing students' learning have been developed. These kinds of theories may be constructed on the basis of specific empirical investigations, from earlier theories in other fields, or based on philosophical commitments.

While the traditional expectation in a natural science such as physics is to use theory as a means of generating hypotheses to be tested, this is most often not the case for qualitative investigations of the social world. Here instead, theory is often generated, extended, clarified etc. through interpretative investigations (Peshkin, 1993), but it can also be used as a general guide for what questions are possible to ask. Researchers in physics and science education often aim at constructing theories in a middle-range, based on empirical inquiries that may be more or less generalizable to other contexts. These are often summarized in theoretical models or frameworks that can be reused and built upon by other scholars, often by revising or adding missing pieces to the models. In my view, one needs to be careful when working with this kind

of model across contexts. In particular, a preference among science education researchers for clear, structured and easily depicted models may serve to oversimplify complex issues.

To take a case in point, in a paper investigating the experiences of women of colour in science, Carlone and Johnson (2007) proposed a model for science identity that has since been used extensively by others researching identity issues, sometimes taken as *the* model for science identity. Carlone and Johnson (2007) identified performance, recognition, and competence as significant dimensions of science identity. For investigating introductory college students, Hazari et al. (2010) added interest to the model to construct a "physics identity indicator" based in questionnaire data. The problem I see with these models is that they at times are adopted as *the* way of talking of science or physics identity, that they are used as general theories for something which should in my opinion be treated with more interpretative care. My work does not aim at proposing or developing such a model or theory for physics identity.

In my use of the theory described in this chapter, I see it rather as providing an underlying necessary paradigmatic dimension for research. By largely subscribing to a social constructionist and qualitative interpretivist research paradigm, theoretical and conceptual presuppositions such as the importance of context or the dimension of power embedded in social relations are taken as a background for my work. In my view, it is important to affirm this basically *ontological* aspect of using theory in research. While theories can be expected to be developed from empirical investigations, they cannot be so without prior ontological assumptions about how the world works. One of the roles of theory is then to provide an ontological perspective on the world and thereby give a ground for how we understand what exists and how it "comes to be" in social reality (Glynos & Howarth, 2007, chapter 4). Poststructuralist theories acknowledge this need for basing knowledge in philosophical standpoints that can never really be "proven" true or false. However, any such standpoint must also always be seen as open to interpretation and contestable (see Glynos & Howarth, 2007, p. 154). My use of poststructuralist and social constructivist thought in this work can be seen as one among many heuristics (Abbott, 2004) for understanding the problems at hand. In this way, part of the theoretical contribution lies in the new questions that are generated when asking: what if we investigate physics identity with a poststructuralist perspective?

3.2 The identity concept

Questions about identity have troubled philosophers and social scientists for a long time. Identity has many meanings, stemming from the literal meaning of "sameness". In philosophy, questions of *personal* identity have been important concerns. These questions regard what it means to be a person, how a person can persist through time, etc. (Olson, 2010). In psychology, questions of iden-

tity have been asked more along the lines of what makes a person specific. Here identity is more related to the concept of *personality*, what makes you *a certain kind* of person. The personality concept has been criticized as having too essentialist connotations (Burr, 2003, p. 106), but these connotations also lie at the root of the concept identity which initially "emphasised innate differences between people, especially in terms of race, class and sex" (Holmes, 2011, p. 187).

In social science, identity is often discussed in collective terms. We have for example *group* identity and *national* identity. The construct *social identity* captures the idea that identity is something that is defined in relation to other people, in social interaction, and one's personal identity is often understood as connected to larger collective identities. Examples of theorizing identity in this way include *symbolic interactionism*, where identities are understood as a "social location" and "the name we call ourselves" (Charon, 2010, pp. 84, 85); Lave and Wenger's *situated learning*, where learning is reconceptualized as, among other things, a "construction of identities" (Lave & Wenger, 1991, p. 53); or different forms of *social constructionism*, where identities are viewed as constructed through discourse (Burr, 2003, p. 105). A more temporary, or "socially situated" identity may be viewed as separate from a more stable "core identity" (Gee, 2011, p. 41), but some social constructionists would deny the existence of any such identity that is *not* socially constructed (Burr, 2003, p. 105).

Several issues regarding the nature of identities arise in these discussions. First, the question of the stability of identity: can people be said to possess a "core identity", which is more or less persistent and perhaps modified over time, or should identity be seen as a temporary construction, always in the process of being constructed, negotiated and reconstructed (see also Pozzer & Jackson, 2015)? Second, and related, the question of whether identity is something someone has a possibility to choose or whether it is something that is imposed from the "outside" (the agency–structure question, see also Shanahan, 2009).

These questions raise the issue of the status of identity: can it be said to be a *property* of a person? And in that case, if identity is a property of a person, what is a person? In philosophy the question of personhood has been discussed using the concept *subject*, which can be defined as a thinking being, the thinking "I" in Descartes' famous phrase "I think, therefore I am". This equating of a human person with a thinking and independent subject who possibly bears identities, the humanist subject, has functioned as the ground for much of western metaphysics and political thinking ever since Descartes, but it has also been the subject of much critique (Hall, 1996, p. 1). For example, philosophers such as Hegel and Nietzsche have raised the issue of how the subject must be considered as formed in relation to others rather than being fundamentally independent (Butler, 1997, p. 3). A radical philosophical proposal in this tradition points out that most of our common languages, in using

the grammatical categories of subject and object, may in fact mislead us in giving too much substance to the subject, to the "I" that "thinks" (Butler, 1990/1999, p. 28).

Although I do not see a need for discussing personhood more deeply in the context of the research of this thesis, this questioning of taken-for-granted ontological categories such as subject and person lies at the base of a *poststructuralist* ontology, and therefore serves as a background for the theories I use. The point here is that we can never fully assume the reality of the categories through which we understand the world—they are in some sense always socially constructed. This means that things such as social reality, how a subject comes to be or how we differentiate between categories, do not bear a stable essence and could always be constructed otherwise. This constructedness is referred to as *radical contingency* in the terminology of discourse theory (Glynos & Howarth, 2007, p. 109; Laclau & Mouffe, 1985/2001).

3.3 Who needs identity?

The classical ideas of subject and identity can be seen as indicating too stable and "essentialist" views of the person, or of cultural groups (Hall, 1996, pp. 3–4). We might even question the usefulness of the term, and ask, as Stuart Hall does in his essay on the question, "Who Needs 'Identity'?" (1996). Hall argues that perhaps one should rather pose the question as a "question of *identification*" (Hall, 1996, p. 2) but quickly notes that this concept of course does not solve all problems either, even though it points more to processes than static entities (see also Pozzer & Jackson, 2015).

Hall nevertheless argues for using "identity" in a new way, "not an essentialist, but a strategic and positional one [...], directly contrary to what appears to be its settled semantic career" (Hall, 1996, p. 3). This view "accepts that identities are never unified and, in late modern times, increasingly fragmented and fractured; never singular but multiply constructed across different, often intersecting and antagonistic, discourses, practices and positions" (Hall, 1996, p. 4). With this understanding, identity can be used in line with social constructionist theories. Vivien Burr, in her text on social constructionism argues for the value of identity as an "implicitly social" concept which "avoids the essentialist connotations of personality" (Burr, 2003, p. 106), seeing no large problems with the identity concept in itself.

A careful use of the "identity" concept thus seems compatible with social constructionist or poststructuralist theorizing. Nevertheless, "identity" in common speech usually implies a "psychological" view of the person, and therefore I often find it useful to talk more of positions than identities. The next section will introduce some poststructuralist understandings of subject formation and how identity is reconceptualized in this tradition.

3.4 Discursive subject positions – a poststructuralist understanding of identity

Instead of taking human subjects as stable and whole, social constructionism "replaces the self-contained, pre-social and unitary individual with a fragmented and changing, socially produced phenomenon who comes into existence and is maintained not inside the skull but in social life" (Burr, 2003, p. 104). This has sometimes been called "the death of the subject", especially regarding the more extreme positions which forecloses "any notion of human agency" (Burr, 2003, p. 121). But perhaps proclaiming the death of the subject is an all too hasty conclusion, and what really has to be done, as Hall, in line with Michel Foucault, urges us to do is to reconceptualize the subject to consider it "in its new, displaced or decentred position" (Hall, 1996, p. 2). This means "rearticulat[ing] the relationship between subjects and discursive practices" (Hall, 1996, p. 2), i.e. asking questions like: is the subject the origin of social practices or is it constituted by them? The answer given by poststructuralist theory is in general negative, it emphasizes the priority of "structure", however, as we will see, this does not mean that agency is impossible. Theorists of the "discursive turn", inspired by Foucault, consider all human interactions as dependent on contingent "systems of representation", or "discourses". In this framework, there can be no "objective", social relations, or "essential" human properties. Central to the discursive turn is that discourses "define what is and is not appropriate in our formulation of, and our practices in relation to, a particular subject or site of social activity; what knowledge is considered useful, relevant and "true" in that context; and what sorts of persons or "subjects" embody its characteristics" (Hall, 1997, p. 6). We cannot know anything outside discourses, and this is emphasized in the succinct and useful definition of the discourse concept given by Davies and Harré (1990):

> In this context a discourse is to be understood as an institutionalised use of language and language-like sign systems. Institutionalisation can occur at the disciplinary, the political, the cultural and the small group level. There can also be discourses that develop around a specific topic, such as gender or class. Discourses can compete with each other or they can create distinct and incompatible versions of reality. To know anything is to know in terms of one or more discourses. (Davies & Harré, 1990, p. 45)

In my analyses, I will often be interested in how specific, local discourses define a "local reality", but also how these interact with "broader" societal discourses.

Seeing subjects as constituted in discourse, Ernesto Laclau and Chantal Mouffe, in their mediation between poststructuralist and Marxist theory state:

> Whenever we use the category of "subject" in this text, we will do so in the sense of "subject positions" within a discursive structure. Subjects cannot, therefore,

> be the origin of social relations – not even in the limited sense of being endowed with powers that render an experience possible – as all "experience" depends on precise discursive conditions of possibility. (Laclau & Mouffe, 1985/2001, p. 115)

This can appear to imply a very determinist picture, where people's being in the world, their subjectivity, is conditioned upon discourse. However, the post-structuralist contribution to this picture, taken on board by Laclau and Mouffe and others, is that this structuring is never fixed, society *can* change, and it *is* changed through human action negotiating the borders of the system. Nevertheless, the notion that discourses actually define our perceptions of reality, and that there is not really anything that can be comprehended outside of discourses is central in this picture: the material world is also given to us through discourse. This notion of discourse does not imply idealism, that thought is the primary existence, or that everything that exists is language. Rather, it points to "the fact that every social configuration is *meaningful*" (Laclau & Mouffe, 1987, p. 82), that we must approach the world through discourses.

While the account of Laclau and Mouffe mostly relates to a macro level of societal discourses, the concept "subject positions" has also been used "in a way that acknowledges the active mode in which persons endeavour to locate themselves within particular discourses during social interaction" (Burr, 2003, p. 113). This is often done by analysing the "positionings" done in talk and other interactions (Davies & Harré, 1990), and these analyses often combine conversation analytical tools with poststructuralist notions of discourse and subjectivity (Wetherell, 1998). These approaches represent a way of recognizing structuring discourses in conversations while at the same time acknowledging that pre-existing discourses are not solely responsible for positioning, but that agency in positioning also arises in interaction (Wetherell, 1998). However, this does not imply total freedom of choice, agency is always constrained by structuring discourses.

A term that is closely related to discourse is culture. Culture has many definitions, and even though some of the earlier work on physics education that I relate to uses it in a mostly anthropological sense (e.g. Hasse, 2002; Traweek, 1988), whenever I use it I mostly draw from cultural studies, where Hall puts the focus on language use:

> To put it simply, culture is about "shared meanings". Now, language is the privileged medium in which we "make sense" of things, in which meaning is produced and exchanged. Meanings can only be shared through our common access to language. So language is central to meaning and culture and has always been regarded as the key repository of cultural values and meanings. (Hall, 1997, p. 5)

Culture can in this interpretation be seen as being constructed mostly by discourse, but also in a sense defining discourse, if we understand language in

the broad sense of signifying systems in general. One distinction that can be made is that it is certainly possible to distinguish different discourses existing in parallel in the same culture, but perhaps struggling for hegemony, in the terms of Laclau and Mouffe (1985/2001). Jørgensen and Phillips, borrowing from critical discourse analysis, call this macro-level of discourses "orders of discourse", and insist on the importance of studying the interactions between discourses in an "order of discourse" (2002, p. 141). As an example, the culture of physics (at a certain place) can certainly be imagined to accommodate several discourses (or even orders of discourse) that define physics and physicists in different ways, which however are intelligible across any single order of discourse. We could for example distinguish between discourses positing physics as a "sacred" search for the inner truth of the universe (see Wertheim, 1995), or as an important endeavour that will provide us with cheap energy in the form of fusion power (always 30 years away).. These discourses embody different underlying value systems, and may thus define our understanding of physics in ways that are conflicting but still comprehensible in a wide physics culture. In my work, which focuses on the construction of subject positions in discourse, I will mostly not go into any detail in distinguishing and comparing different discourses that may exist in physics culture.

3.5 Performativity and subjectification – problematizing agency and structure

Judith Butler has been one of the most influential scholars in the establishment of a discursive understanding of identities, particularly gendered and sexual identities (Hall, 1996, p. 14; Holmes, 2011, p. 188). She has elaborated the Foucauldian view and brought a psychoanalytic notion of identification into the theory. In *Gender Trouble* (1990/1999) (and in *Bodies That matter,* 1993/ 2011), Butler puts forth a *performative* account of how gender and sexuality are established and sustained. In line with the discussion of how grammar may mislead us to grant too much substance to personal categories, Butler argues that: "There is no gender identity behind the expressions of gender; that identity is performatively constituted by the very 'expressions' that are said to be its results." (Butler, 1990/1999, p. 33) This is coupled with a questioning of the distinction between sex and gender. Butler poses the question if not "this construct called 'sex' is as culturally constructed as gender" (Butler, 1990/1999, p. 10). Taken together, this suggests that identity on all levels (even the purportedly neutral biological factors) are discursive and stabilized by the power of discourse, but at the same time subject to change through continuous small acts of subversive performativity, i.e. "failed", "wrong", or "parodic" repetitions of expected gender (etc.) behaviour. Subversive performativity is one way of conceptualizing agency in this otherwise strong picture of the structuring effect of social norms. While agency is circumscribed, resist-

ance is possible through what can be called the "cracks and fissures" (Carlone, Johnson & Scott, 2015) in the structure, the always incomplete closure of the social (Glynos & Howarth, 2007), or "[t]he possibility of choice in a situation in which there are contradictory requirements" (Davies & Harré, 1990, p. 59).

Another important aspect of Butler's account builds on the recognition that subjectivity always depends upon a disassociation between the self and the other. Parts of this disassociation take place on the level of discourse and for Butler this means that, as Hall puts it, "all identities operate through exclusion, through the discursive construction of a constitutive outside and the production of abjected and marginalized subjects, apparently outside the field of the symbolic, the representable" (Hall, 1996, p. 15). In Butler's account, what are viewed as "intelligible" subjects and identities "inside" discourse are structured by normative power relationships and she posits that for instance "'[i]ntelligible' genders are those which in some sense institute and maintain relations of coherence and continuity among sex, gender, sexual practice, and desire." (Butler, 1990/1999, p. 23) This assumed coherence that constructs some identities (e.g. gay and trans*) as more or less "unintelligible" is usually referred to as "the heterosexual matrix" (Butler, 1990/1999, Note 6 to chapter 1, p. 194). The notion of intelligibility is not only useful in discussing gender and sexuality, but can be usefully brought into discussions of what it means to perform an "intelligible" physicist subject position (see e.g. Gonsalves, 2014 and the discussion below), and this is where it becomes important for me.

In a later work, *The Psychic Life of Power* (1997), Butler engages further with the question of *subjection* (or *subjectification*), i.e., the process whereby subjects are produced. She paints a picture where achieving subjecthood implies a process of mastery, "indistinguishable from submission" to social regulatory power, and where to "desire the conditions of one's own subordination is thus required to persist as oneself" (Butler, 1997, p. 9). One of the important points of this treatment is that a, or "The", subject should never be used as a synonym to "person" or "individual", but rather "ought to be designated as a linguistic category, a place-holder, [...] the linguistic occasion for the individual to achieve and reproduce intelligibility, the linguistic condition of its existence and agency" (Butler, 1997, p. 10). This means that the notion of a person is not something that necessarily exists prior to its representation in language, at least not as an intelligible concept.

Butler's developments leave us with a picture in which persons are subjected into discursive subject positions and in that way become intelligible subjects in discourse. I suggest that this process can be viewed on different levels: a more fundamental level of becoming an intelligible person with expected gendered, sexual (etc.) identities, and a more contextual of achieving intelligibility in certain contexts, e.g. becoming "a 'good student,' a 'good cook,' a 'gang member,' a 'competent lawyer,' a 'real basketball fan,' or a 'real Catholic'" (Gee, 2011, p. 34). I believe that this contextual view of intelligible subject positions is especially valuable for education research. Taking

departure in a developed poststructuralist notion of identity, it emphasizes the power-permeated discursive construction of educational subjectivities.

3.6 Doing education research inspired by poststructuralist theories

Having outlined the background for my approach to identity studies, I now turn to how this can be used and has been used in educational research. In particular, how such an understanding of identity can represent one way of bridging the structure–agency dialectic.

In a poststructuralist view of identities, taking on an identity means to be subjectified into more or less defined subject positions. On the one hand, this idea rejects a voluntarist account where identities can be chosen at will by a free agent. On the other hand, it also steers clear of a totally deterministic picture where a subject has no agency at all. This means that discourses are constructions that can be reconstructed, and they are reconstructed in the continuous performances of subjects acting within them (Davies & Harré, 1990; Glynos & Howarth, 2007). Using these theoretical developments thus provides one way for educational research to pay appropriate attention to the interaction between agency and structure.

One approach to using these thoughts is to discuss how "educational subjectivities" are formed. Bronwyn Davies, in a paper describing the merits of the concept of subjectification for studies of identity in education, argues that subjectification viewed in terms of mastery/submission is a useful model in school contexts. Thus, to "master" something in school, means to submit to the discourses of this topic and what a "good" student of it should be; to be recognized as a legitimate "school subject" means submission (Davies, 2006).

Other educational researchers have taken up the notion of intelligibility and asked what subject positions are constructed as intelligible in the discourse of certain areas. One example of what this can entail is given in a study by Solli, Bach and Åkerman (2014). This study demonstrates how certain dispositions/thoughts/ways of being are excluded from an identity as a biotechnologist through the discourse in undergraduate biotechnology education. Specifically, political-economic rationales for opposing GMO are excluded from the discourse, presenting GMO opposition as mostly irrational and unavailable to students (supposedly) striving to be scientific, rational and objective biotechnologists (Solli et al., 2014). Here we see how the construction of intelligible identities requires boundary making, the construction of a constitutive outside of irrational, unintelligible positions.

A similar focus on intelligible subject positions is taken by Gonsalves. As described in Section 2.5.5, her study of physics doctoral students shows how certain positions as a physicist are more intelligible and that being a female physicist involves navigating positions that generally exclude stereotypical

femininity. Other studies have focused on the performativity of identities and also paid attention to the ordering of several intelligible subject positions in classrooms. Carlone, Scott and Lowder (2014) and Archer et al. (2017), analysed school classroom interactions to outline how certain subject positions (or identity performances) are more *celebrated* than others. The results point to how school students struggle to align with celebrated subject positions in school science, like being a "good" and engaged student. In particular, being a good student intersects with classed, gendered, and racialized identity performances, and the possibilities for negotiation are slim (Carlone et al., 2014). Carlone et al. (2015) describe what happens to some of the students in their study in terms of formidable social structures overcoming agency, when an initial alignment with science clashes with expectations of stereotypical female gender performances and eventually renders the girls as "non-scientific". Archer et al. (2017) found similar patterns, and describe the celebrated identity performances in the classroom they analysed as: adapting to standardized testing, behavioural compliance, and doing confident and arrogant assertions of knowledge and intelligence. They discuss how the individual classroom gets structured by an assemblage of influences: education policy, the school and its teachers, and social norms about gender, class etc.

In educational research on identities using a poststructuralist theoretical framework, earlier taken-for-granted humanist ideas about the subject are questioned. Identity is re-imagined in terms of discursive subject positions achieved through processes described as subjectification, positioning, or performances, related to more or less already established discourses. The concept of identity is here treated with caution, and in general, it is essential to avoid talking about identities as possessed by actors (Pozzer & Jackson, 2015). Departing from this background, the aim of my project is not to define and evaluate students' "physics identity" (as is implied in the work of e.g. Hazari et al., 2010). My primary focus instead lies in analysing what positions are made intelligible in local discourses of physics education, and how students relate to these positions. In this way my work pays attention to the *conditions* for students' identifications as physics people.

3.7 The measurement problem in studies of identity

Having described the poststructuralist and discursive concept of identity that I will be using, it is valuable to highlight how this relates to other ways of conceiving of identity. In this section, I will do this using a metaphor drawn from quantum physics, in the hope that this will be illuminating for both physicists and other readers. In doing this, my aim is to illustrate how the different ontological and epistemological premises for a poststructuralist account of identity as opposed to a more humanist may be similar to the difference between conceptions of classical and quantum particles. However, I do not aim to suggest

any substantial connections between these concepts other than the metaphorical here (although I recognize that such ideas have been taken seriously by others, see Barad, 2007).

As I have already discussed at length, drawing from the discussion of among others Pozzer and Jackson (2015), I believe it is not conducive to my goals to regard identity as a property which people possess. While some researchers have attempted to operationalize identity as a measurable variable in attitude surveys (Hazari et al., 2010), I believe that this measurement is too easily understood in terms corresponding to classical physics. That is, as measuring a (more or less) inherent property of someone. I suggest that "measuring" identity, if regarded in poststructuralist terms, perhaps could better be understood by comparing it to a quantum measurement.

In quantum mechanics, when measuring some observable of a quantum particle, we get a fundamentally probabilistic result. While this is usually understood to imply a temporary "collapse" of possible future outcomes of a similar measurement, a subsequent measurement of another, non-commuting, observable may "destroy" the acquired information about the first measurement. That is, different measurement apparatus bring out different (possibly incommensurable) features of a quantum entity.

When studying what we might want to call someone's identity or "physics identity", we are in a similar way performing a form of measurement. This "measurement" brings out a particular aspect of how someone identifies themselves, in relation to the context (the measuring apparatus) which currently makes this aspect manifest. This context is given by discourse and an "identity measurement" corresponds to positioning, to someone taking up and aligning with a discursive subject position. Similar to quantum particles, it is problematic to claim that this "identity" is something that a person possesses, other than perhaps temporarily. This can be compared to the problem with hidden variables theories, which have proved generally inconsistent for quantum entities. In this metaphor (and in quantum mechanics), measurement is not something that only researchers do, but rather something which happens all the time as particles/people interact (and decoherence occurs). In a sense, to local observers, a person's identity may appear "classical", i.e. determined as a single value, even though discourse in general (or the global wavefunction) is always open (or behaves quantum mechanically).

A few examples of this process are given in this thesis. We can say that when students interact with the courses they take, some aspects of identity are brought out and some subject positions are taken, in relation to the "measurement apparatus" of the local discourse. On the other hand, when going home from the university they may well perform many different identities related to other subject positions more intelligible in discourses outside the university.

The point is that we need to view identity as something that arises in interaction. On the one hand, we can perhaps assume that there is *something* that connects a person from one moment to the next, that distinguishes a person

and makes them in some sense "the same" through time (something that cannot necessarily be claimed for quantum particles, where for example all electrons are *identical* and indistinguishable). On the other hand, the expressed negotiations, narratives and acts are perpetually new "doings" of identity. In a strict reading of Butler (1990/1999), these "performances" of a stable identity are all there is, and they produce the illusion of a consistent, intelligible person with certain (gendered, sexed, etc.) identities, and perhaps this view of the person coincides more with a quantum mechanical picture than we usually assume (or are comfortable with).

Once again, these metaphors should not be brought too far. In particular, I do not mean to claim that social interactions would be nearly as quantifiable as physics phenomena at a deeper level. In my opinion, that would again leave us with a too reductionist approach to social science.

3.8 The role of the critical researcher

I have repeatedly stressed the importance of employing a critical perspective on research, but what does this mean? What is the role of critique and of the critical researcher in education studies?

At the outset, a critical mindset can be seen as the basis of all science. For example, the readiness to disprove hypotheses in Popperian falsificationism (Popper, 1959/2005) represents one way in which scientists are expected to be critical. However, the notion of social critique, as formulated for example in "critical theory" (Horkheimer, 1937/1975) is not as commonly embraced. In gender studies and related fields, issues of power and politics are often seen as inherent in all social interactions, and this implies a critical perspective. The argument is that using a critical perspective, grounded in political standpoints and not being afraid to admit and account for it, is actually essential for giving nuanced pictures of the world, and potentially changing it (see also discussions of standpoint epistemology and situated knowledge, Haraway, 1988; Harding, 1986, 1993; Rolin, 2009).

Nevertheless, there are some subtleties that need to be discussed when it comes to critique. Doing critical research cannot only involve criticizing (or critiquing) for its own sake. It is easy to take on a critical attitude where the task is to reveal, find faults, and point out underlying villainy. This has been called a "hermeneutics of suspicion" (Felski, 2015). However, in discussions critiquing this form of criticism, the point has been raised that you can never stand outside or above what you analyse, to critique and easily pass judgement on it. A particular issue with the suspicious form of critique is that the object of critique, which is often common-sense knowledge or practices, is put in a position as false, constructed, and poorly justified, directly influenced by something deeper, which is hence seen as more true. The problem with this reasoning is that the truths of the critic are then supposed to be unquestionable

facts that are themselves exempt from critique. Bruno Latour problematizes this classical "debunking" form of social constructivist critique and argues for a more constructive approach (Latour, 2004), and I agree.

Another take on the role of the critic is given by Foucault, who by Butler (2008) is read as posing the task of critique not as pointing out what is wrong, according to some self-evident value-system, but rather to momentarily "suspend judgement" and ask: How has the prevailing order been established? What maintains it? How could things be different? There are seldom any obvious answers to these questions, but critique can at least then have managed to open new possibilities for conceptualizing taken-for-granted practices. Even when attempting to do a more constructive critique, it is not necessarily the task of the critic to come up with finished solutions (compare this to the expectation on PER researchers to be "resource people" Heron & Meltzer, 2005, p. 392). Rather, there is a value in "making it so that what is taken for granted is no longer taken for granted [and] to make harder those acts which are now too easy" (Foucault, 2003, quoted in Bazzul & Carter, 2017, p. 445). This means that, on the one hand, we cannot demand ready solutions to what is identified as problems in society, neither from critical investigations, nor perhaps from any kind of basic research. On the other hand, it is important to avoid doing the kind of "subcritical" critique which Latour, inspired by Alan Turing, describes will, when given a single idea as input, "on average give rise to less than one idea in reply" (Turing, 1950, quoted in Latour, 2004, p. 248). Doing critique should inspire new questions and solutions, and this is what I hope to do with my research.

To show where I aim my critique, I will take a concrete example from my research: the issue of too much "calculating" in quantum mechanics education that is discussed in Papers II and IV. Does this mean that I have identified a singular problem that should just be removed from physics education. Of course not! As every physicist would agree, the mathematical formulation of quantum mechanics is entirely necessary to understand and use it to any depth. What does it then mean to "criticize" calculating in quantum mechanics? I do not aim to throw out the baby of learning the strict theoretical formulation of physics theories with the bathwater of excessive calculating practices. Instead, the point is that the practice of extensive calculating that is described in Paper II can also limit the possibilities for students in some ways which we as physicists may deem as unfortunate. With this kind of intervention, I aim to raise *more* questions, both for researchers and practitioners. Questions like: Why do we focus on this practice? Do we need to do it this way? Who benefits? Who does not? How is a successful physics student conceived of in this structure? What does it mean to do physics? What is a physicist and what can a physicist be? And while I do not present a "magic bullet solution" for the physics instructor to employ, I do believe that several of the ideas for reformed quantum mechanics teaching that I discuss in Paper IV are steps on the way towards achieving more inclusive physics education.

4. Methodologies for studying discourse

This chapter details how a discursive view of identities has informed my research, and the methodological traditions I have drawn from when collecting and analysing data. The next chapter describes the material and methods for each of the studies in more detail.

4.1 Studying discourse and identity

With a poststructuralist, discursive view of the social world and identities (or subject positions), we need tools to study discourse in one way or another, to be able to say something about the context in which the positions/identities we want to study are enacted. Several different approaches for analysing discourse exist, with different theoretical commitments. Jørgensen and Phillips (2002), in their instructive book on approaches to discourse analysis, separate three directions, "Discourse theory", "Critical discourse analysis", and "Discursive psychology". They describe the varying focus of these approaches, from macroscopic political discourses (discourse theory drawing from Laclau & Mouffe, 1985/2001) to interpersonal interactions (Discursive psychology), and the varying scope of "discourse" used, from a completely social constructionist standpoint where the material world cannot be conceptualized outside discourse (Laclau and Mouffe) to discourse as just one social practice among others (Critical discourse analysis as put forward by Norman Fairclough). Although discourse analysis is not just a method, but rather "theory and method" or "a complete package" as Jørgensen and Phillips (2002, p. 3) claim, it is possible to blend different perspectives and create "one's own package" (p. 4) as long as the theoretical commitments match the methods used. In my work I have combined and used different perspectives and tools for analysing discourse. In particular some of the tools of discourse analysis described by Gee (2011), were used for the first papers. Gee, while inspired by critical discourse analysis, is especially pragmatic in his approach to discourse analysis, blends several perspectives, and also encourages a dynamic re-use of his tools (Gee, 2011, p 11). In Papers I and II Gee's "building tasks", micro-analytic tools for analysing enacted discourse, were used to focus on what was constructed in the studied contexts. In Papers IV and V, a slightly broader approach, focusing more on the discourses interviewed students referred to and negotiated was employed.

4.2 Knowing discourse

Analysing discourse means doing a kind of qualitative research, in an interpretive, hermeneutic tradition. This means that results are neither absolute truths nor totally subjective opinions. The questions one should ask of interpretive qualitative research are not questions of validity and reliability, but of trustworthiness (Taylor, 2014, p. 44): Are these interpretations reasonable given the "data"? Is the researcher honest in accounting for the production of the results? Additionally, in studying discourses with a social constructionist perspective, researchers can never properly be "outside" the discourses they study and observe them in some kind of "objective" way. Jørgensen and Phillips describe the role of the discourse analyst as one of methodically "distancing" oneself from the material and trying to reflexively analyze "taken-for-granted" meanings (2002, p. 21).

The closeness to the research context is of course a particular issue for me, as I have been enrolled in similar classes and programmes to the ones I am researching. This may be seen both as an asset (making it easier to understand the context) and as a burden (risk for over-familiarity or bias). However, reflexivity and an awareness of the situatedness of knowledge is one way of alleviating these risks. Social epistemologies put forth by feminist philosophers have been highlighting the role of the social (and power-) relations between researcher and researched for the results of research. In particular, feminist discussions of epistemology have pointed to how all knowledge is "situated". In this tradition, Donna Haraway asserts that claiming knowledge from a "disembodied", "objective" position is a power move, a "god trick", which hides how all knowledge is produced under specific social and political conditions (Haraway, 1988). What we should aim for instead is recognizing our situatedness and its role in producing knowledge. As Haraway puts it: "The moral is simple: only partial perspective promises objective vision." (1988, p. 583) This means that to practice "objective" (or good, qualitative) research for me is to be reflexive, taking my position in regard to research subjects and others into account.

A final point that needs to be made regarding the production of knowledge of discourses is the question of what a discourse "is". Jørgensen and Phillips argue for treating discourses and the delimitations between them more as "analytical concepts" than entities existing "out there" (2002, p. 143). This avoids some tricky ontological questions, but I nevertheless want to maintain that the discursive "patterns" that I outline in the papers are "there". However, the delimitation of these different discourses, discursive practices, positions, or identities are of course also analytical choices. This means recognizing that while discursive patterns can be understood as being "articulated" in certain ways by social actors, the researcher is also a part of articulating discourse, thus affecting how we understand the world, something which also implies an ethical responsibility (Glynos & Howarth, 2007, chapter 6).

4.3 Terminology: discourse, identity, and subject positions

One thing that has to be sorted out in my approach to a discursive view of social identity is the terms used and how I define them. The papers represent slightly different ways of talking about identity and discourse, using identity, discursive position and imaginary position at various points of writing. Of course, this in part represents the development of my own thinking about these issues. However, my interpretations have always intended to apply a consistent post-structuralist understanding of discourse and social construction to these concepts.

In general, I have taken discourse to mean "an institutionalised use of language and language-like sign systems" (Davies & Harré, 1990, p. 45). It is important to note here that discourse does not only refer to language, but social meaning-making in general. To emphasize this linguistic and extra-linguistic nature of discourse, Gee, uses a concept of "Discourse" with a big "D", which is distinguished from merely linguistic discourse, with "a little 'd'" (Gee, 2011, p. 34). Even though I use Gee's tools for discourse analysis, I will not maintain this distinction but rather in general always consider discourse to contain more than just spoken language. Nevertheless, spoken language is often the main focus of my analytical work.

In Paper I, "identity" is used in line with Gee's usage of the term, as one thing among others built in language, used to denote "who" someone is (Gee, 2011, p. 2). Identity is viewed as socially constructed and produced in the interaction of the interviews, but the identities that are enacted by the students can still be taken as part of larger groupings or "cultures", which the students themselves refer to. In the analysis of this paper, students are shown to construct identities and practices related to groups such as study programme and gender.

In Paper II, instead of "identity" the object of study is defined as "discursive positions". This is because this study focused particularly on possibilities made available in discourse and not in detail on how students negotiated them. The discursive positions that are described are inferred in the general discourse of the courses (strongly related to "practices") and are not necessarily "lived" or "performed" identities that any student takes on for a longer or shorter time. The choice of using "discursive position" instead of the more established concept of "subject position" is motivated by the fact that "subject position" can be seen to imply a too strong structuring of subjectivities, a claim I want to be cautious to make in this context.

In Paper III, which is a conference paper for PERC, "identity" is used again. This is primarily because "identity" is a generally recognized term in the physics education research field. Since the paper is an argument about refining and nuancing the use of identity perspectives in PER studies, I believe it is important to keep to common terminology. Similar considerations were used

in writing Paper IV, which is aimed at a mixed audience of physics educators and researchers. In this paper, identity is not used extensively as a theoretical construct but when using it I emphasize the need for students to negotiate identities in relation to their study choice. As the analysis in that paper lies close to the stories of the interviewees, their emotional attachments to various positions become important. In Paper V, I further highlight the interactional aspects of identity by writing about negotiations of "imaginary positions" (inspired by Wetherell & Edley, 1999). The point here is to emphasize how identity is constructed and negotiated through positions in discourse whilst at the same time avoiding the trap of ascribing specific identities to people (Pozzer & Jackson, 2015).

In summary, I find the use of the identity concept a complex issue with many pitfalls, and generally prefer to rather talk about positions in discourse. Nevertheless, identity is important, and perhaps continuing to use the identity concept, perhaps in "its new, displaced or decentred position" (Hall, 1996, p. 2), is a way of keeping the significance it has for people in sight.

4.4 Studying enacted discourse: methods

The approaches taken in the papers all aim at exploring how physics students are "formed" in relation to the discourses of physics education. To be able to analyse these discourses, some representative material has to be collected, and the two methods for doing this that I have used are participant observation of classes and other activities, and single and group interviews with students. The field notes, recordings and transcripts from these activities were then the main material used for analysis. This section will expand on each method, and its merits as a means of studying discourse.

4.4.1 Participant observation

Participant observation as a method has been used for a long time by anthropologists doing "ethnography", and has since been adopted in many fields. Traditional ethnography, as it is understood in anthropology and parts of sociology, has long intended to give an understanding of how a studied culture "works": "that is, to grasp what the world looks like to the people who live in the fishing village, boarding school or mining community" (Delamont, 2012, p. 343). Traditionally, it has been informed by a naturalist epistemology, where the researcher should study the social world in a "natural state" to be able to give an account of the social workings of the specific studied context that is as true as possible (Hammersley & Atkinson, 2010, p. 7). This implies a social realist view of the social world, as something lying out there being "discoverable" for a researcher (Hammersley & Atkinson, 2010, p. 13). However, my aim has not been to write "an ethnography" of physics education,

and get a broad understanding of how this social context "works" (this has in part been done by others, see e.g. Hasse, 2000), but rather to examine the discursive productions in a few specific contexts of physics education. I would also like to avoid the classical naturalist epistemology of ethnographic research. In educational research, ethnographic studies are usually not as extensive as in anthropology and sociology, and certainly not as immersed as the round-the-clock-living-at-the-field-site, anthropological variant of ethnography (Delamont, 2012, p. 343). I have followed this tradition and mainly borrowed parts of the methods of ethnography in a "light-weight" participant observation.

My familiarity with the setting (having taken many similar physics classes) has allowed me to focus on the specific discourses at play in the classroom rather than struggling to understand an unfamiliar context. Of course, there are also possible problems with knowing and assuming too much about the situation. Sara Delamont, in discussing ethnography in education, describes the most common problems of observation in educational settings as "over-familiarity and boredom" (Delamont, 2012, p. 345). This has also been my impression at times. However, using discourse analytical tools on the collected material has allowed me to distance myself from the context and discover patterns that were not obvious at the outset.

The concrete process of participant observation involves taking structured fieldnotes (Emerson, Fretz & Shaw, 2011). This often means jotting short notes for memory on paper, in a way that avoids disturbing ongoing activities, to be able to later collect these remembered events into structured and readable notes. While doing this and in the following analysis processes, the researcher's reflections and thoughts are collected into structured field notes and memos (Lofland, Snow, Anderson & Lofland, 2006). In the classrooms I have observed, taking notes is a very common behaviour, so I have been able to take extensive jottings, which I have compiled into structured notes as soon as possible afterwards.

4.4.2 Interviews

To get a detailed view of students' negotiations of identities, I have used semi-structured individual and group interviews. From a social constructionist perspective, when doing interviews, the performative co-construction of meaning between researcher and interviewee should be taken into account. This has been realized, for instance in ideas such as "postmodern interviewing" or "InterViews" (Gubrium & Holstein, 2003; Kvale & Brinkmann, 2008; Taylor, 2014, p. 48). What is captured in an interview is thus not an objective insight into the true experiences of the interviewee, but rather a discursive performance, that is, a representation of certain identities, "facts" and views, which are dependent on the situation and created in interaction, even though they may

draw from discourses outside the specific situation. With this epistemological grounding, the purpose of carrying out interviews is not to get trustworthy information about "how it is" from interviewees, but rather to gain samples of discourse in action, in particular for me: performances and negotiations of identities.

4.4.3 Analysing discourse

To analyse the discourse in the material from observations and interviews, I have used several methods. In a sense, an interpretative analysis starts already when starting to do the research, even before research questions are formulated, and continues through the collection of research material to the writing and publishing itself. In between, though, there is the process of sorting through the material and trying to find discursive patterns.

In the projects taken on for this thesis I have used a few different approaches to analyse the material. These have mostly taken departure in a process of open coding (Flick, 2009), where I have started coding pieces of the material already when compiling notes or transcribing interviews. To help with the technical side of this process I have developed a custom library for the text editor Emacs that has allowed me to easily extract, list and export coded sections.[1] Coding in this way and revising codes allows the researcher to gain access to the material along various dimensions, and this is the primary use to which I have put my coding schemes (rather than using them as the basis for "constructing" theory, as can be done in grounded theory, see Flick, 2009; Strauss & Corbin, 1998). At times, coding itself can be seen as complete analysis and the reporting of codes (and their incidence) as a reporting of results. This can however imply a limited, "quantified", view of qualitative data (Hammer & Berland, 2014). In my analyses, codes are used for sorting data as a starting point for a more interpretative, hermeneutic analysis.

In the analyses I have used a few different tools and concepts to further break down the material. The "building tasks" of discourse described by Gee (2011) have been used for the analyses of Papers I and II. Gee writes:

> Whenever we speak or write, we always (often simultaneously) construct or build seven things or seven areas of "reality." Let's call these seven things the "seven building tasks" of language. In turn, since we use language to build these seven things, a discourse analyst can ask seven different questions about any piece of language-in-use. (Gee, 2011, p. 17)

Gee lists the building tasks as: "significance", "practices", "identities", "relationships", "politics", "connections", and "sign systems and knowledge" (2011, pp. 17–20), and puts forward several questions to ask of "language-in-use" to find out what it is building. In Papers I and II I have used Gee's

[1] This library is available at http://gitlab.com/andersjohansson/orgqda.

questions for "practices", "significance", and "identities" and the connections between these building tasks to analyse what identities (or discursive positions) are communicated in the material. The notion that a practice always implies an identity, a "who-doing-what" (Gee, 2011, p. 30) is particularly illuminating in this context, since it allows the analyst to connect constructed practices with identities. Using building tasks in the concrete analysis, then means asking specific questions of the material along the lines of: What is constructed here? How? What does that mean? For example, this can be: "What practice (activity) or practices (activities) is this piece of language being used to enact (i.e., get others to recognize as going on)?" (Gee, 2011, p. 18).

In analysing the interview material for Papers IV and V, I have used a more general thematic analysis (Bogdan & Biklen, 2007). Here, the initial coding was used for developing emerging themes, where specific discourse analytical questions could be asked. For example: What is constructed as essential to being a physicist? Are some of these discourses contested? Comparisons between interviews could then be done and common themes for the material described.

The subsequent stage of analysis comes in writing. In formulating my interpretations in words, another phase of critical evaluation takes place when I, my collaborators and colleagues who may read the text can question and discuss the analyses. Questions to be asked at this stage are: Is this interpretation reasonable given the material? Is there some other explanation? This complete process of sorting, analysing, writing, thinking and revising represents one way of doing the hermeneutical interpretative work that is required in qualitative research.

4.4.4 Using mixed methods

Paper I, apart from discourse analysis of interview material, uses statistical analyses of student grades as a starting point and a confirmation of the notions expressed by the students, and is as such a case of "mixed methods" research. Mixed methods is sometimes viewed as a way of going beyond dichotomizing distinctions between qualitative and quantitative research that are "not only unproductive but fallacious" (Treagust et al., 2014, p. 13; see also the discussion about pragmatic method choice in PER, by Robertson et al., 2018). Mixing various types of data is claimed to result in more precise results through the notion of "triangulation" (Treagust et al., 2014, p. 13). However, triangulation "does not necessarily serve the epistemological interests of interpretive researchers" (Taylor, 2014, p. 44). Instead, it may once again reinforce the notion that quantitative methods and the criteria of validity and reliability are the norms which all research must live up to (Taylor, 2014). This can for example be seen in the common "misunderstanding" that qualitative case studies

are good mostly for generating hypotheses and ideas for other more "rigorous" research (Flyvbjerg, 2006).

In Paper I, the qualitative results are as central as the quantitative. The paper is an attempt to answer the question "Why do women have lower grades in the Electromagnetism course?", but even though a quantitative answer can be given in the form "it is a programme gap rather than a gender gap", that is not the end of explanations. As we show, in understanding students' negotiations of course practice, attention must be paid to negotiations between identities and cultures, both at the local, institutional level and on a society-wide level. Paying detailed attention to these issues needs to be done in a qualitative, interpretative way.

4.5 Conducting ethical research

Research should not only be well-designed and answer significant questions, it has to be carried out in an ethical way as well. Some of the ethical considerations involved are codified in international guidelines. My research has followed guidelines for good scientific practice and research integrity set up by the European science foundation, as well as local codes of conduct and applicable laws in the countries where the research was conducted.

A major concern when conducting research with human participants is the potential of causing harm in some way. For research of a social nature, this potential harm is mostly conceived of as social or psychological. Do I risk disproportionately upsetting or disturbing my participants? In social research, it is hard to predict the effect of being present and talking to informants. There is no way of not "changing" people in some way, everyone comes out from each social encounter having some new experiences that influence their being in the world. Nevertheless, in my research projects I have aimed to avoid making people upset or uncomfortable, and especially committed myself to not unduly "disturb" any ongoing activities. This means for example carefully planning together with teachers and others when I should inform about the projects etc. The research topics brought up in interviews have aimed to explore students' social identities as physicists/physics students. While this subject can at times be emotional or sensitive, I have let the interviews develop dynamically, following what students are willing to talk about, and in that process attempted to be responsive to their emotions and choices.

Of particular importance when conducting this kind of research are the conditions for participation. All participants in the research should be able to, based on an informed understanding of the research project, make a decision about whether they want to participate or not. I have throughout my projects informed all participants about the background and goals of the project, how the research will be conducted, the conditions of their participation and the treatment and storage of the data. See Appendix A for an example of the in-

formation letter serving as a basis for students' consent to participate in the interviews for project 3.

Another possibility of harm comes from the disclosure of personal information and to avoid this I have consistently used pseudonyms and other measures to avoid the possibility of participants being identifiable. All material in collected field notes and interview transcripts have been coded with pseudonyms, and other information that could reveal people or contexts (like locations, or too exact descriptions of environments) has been avoided. For the same reason I have also generally avoided naming the institutions where research has been conducted in published material. However, keeping the identity of the institutions hidden to any sufficiently devoted inquirer is of course impossible. All material has been archived and handled in secure ways according to applicable laws and guidelines. Throughout the research projects, I have aimed to continuously reflect upon my practices and their ethical consequences.

In my view, research ethics concerns not only avoiding harm for participants, but also providing benefit, and it is not something that is done once and then completed. Doing critical or postmodern research, ethics concerns the aims and results of research as well as the methods (Taylor, 2014). In this paradigm, one conceptualization of ethical research is the possibility of critiquing prevailing norms and opening up possibilities for imagining things to be otherwise (Glynos & Howarth, 2007, p. 197). The aim of my project is clearly emancipatory. In the long run, my work is motivated by problems of unequal participation in science, but this does not mean that it is necessarily beneficial or risk-free for the participants. Nevertheless, I do hope that my project can contribute to a greater good. In the end, the good of the project itself can perhaps not be judged before it is published and reused and maybe makes a difference somewhere.

5. Data collection and analysis

The papers presented in this thesis are based on data collected and analysed in three separate projects. This section will describe the collected data and analysis procedures in detail, while in-depth examples are given in Appendices C to E. An overview of the data, analyses and papers is presented in Figure 5.1. All the three projects address identity issues in physics education by using a discourse perspective, but with slightly different approaches and empirical focus. In particular, the focus shifts between analysis of students' accounts of their experiences in interviews and analysis of discursive constructions in observed classroom practices.

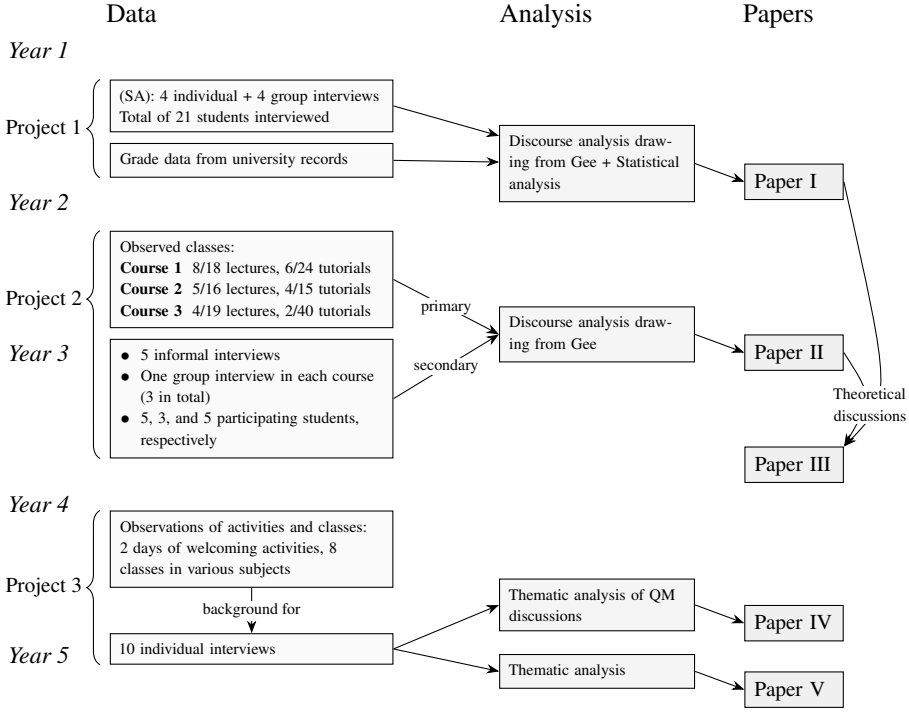

Figure 5.1. Overview of projects, collected data, the analysis conducted on each dataset, and the papers where the findings were published.

5.1 Project 1: identity in electromagnetism

5.1.1 Data collection

This project, reported in Paper I, draws from data which Staffan Andersson, my supervisor at the time, collected when asked by the university to investigate an apparently consistent gender gap in the results of the Electromagnetism course. To explore the issue, Staffan conducted four individual and four focus-group interviews, all semi-structured, which we subsequently analysed together. The students were interviewed after having completed the course and the interviews proceeded in three stages: discussing general study experiences, particular experiences of the course and achievement in it, and finally gender issues. Along with this material, we used university records of grades, gender, and study programme for the students passing the course from the autumn semester of 2007 to spring 2013 (where the course was given several times and for different groups of students).

5.1.2 Analysis

The interviews were transcribed and subsequently analysed using an interpretative discursive lens drawing from the tools developed by Gee (2011). In particular, we used the notion of "building tasks of discourse" to focus on how students' constructed "significance", "practices", and "identities" in the talk of the interviews. The analysis meant comparing and contrasting the various utterances of the students, drawing out how they related to the course and what kind of practices they described themselves as adopting in relation to it. An example of this analysis can be seen in this quote from one of the students: "Electromagnetism is really core physics. As physics is supposed to be the brand of my program I made sure to learn it properly." Here, a practice of "learning it properly", or as we call it in the paper "studying to learn" is indicated. This relates to the vocational significance of the course as something belonging to the Engineering Physics programme the student is enrolled in. At the same time, it constructs the speaker as someone belonging to the group of engineering physicists, i.e. having some sort of "physics identity". The general picture in these analyses was that students constructed and negotiated identities which were more complex than simply following gendered stereotypes, which they often opposed, and instead emphasized different interests and focus in studies. In analysing the grade statistics, using two-tailed t-tests for comparisons, we could corroborate this picture to point to the problem as a "programme gap" (see discussion of results in Section 6.1). In writing the paper and revising it after the extensive reviewer comments we received, we could further sharpen the analysis and the knowledge claims made.

5.2 Project 2: discursive practices in quantum mechanics teaching

5.2.1 Data collection

For project 2, reported in Paper II, extensive data collection was conducted in three introductory quantum mechanics courses. Here, aiming to capture what discursive positions were available for students in the enacted discourse of the courses, I used participant observation of classes combined with a limited number of interviews with students to focus on what the courses provided.

The participant observation methodology was inspired by ethnography. The approach used was however not as all-encompassing as is normally thought of in ethnography (mapping of a local culture). Rather the study focused on the specific discourse in the courses, what was communicated during classes and how students could be expected to make sense of their practice in the course. At first, I carried out observations of lectures and tutorials in one course (mainly taken by physics bachelor students) during one semester. I participated in lectures, problem solving sessions and a few labs, and during this time did a few informal interviews with students. During the observations, I scribbled notes, focusing primarily on what was communicated to students through the teaching and other means. The notes contained quite a few more or less verbatim quotes from teachers and students, but also descriptions of situations, environments and actions. The analysis of this kind of material usually starts already at the stage of collecting it and this was the case here as well. After each session of observations I expanded my scribbled notes into more extensive field notes, and in this process I wrote shorter reflective notes and research memos, as well as a first coding of sections.

To probe student perspectives on the course, I conducted one focus group interview with a self-selected group of students on the course. The interview was semi-structured and I initiated the discussion with a few questions about the students' general experiences of studying on their particular programme, about studying the quantum mechanics course and about what it means to be a physics student/become a physicist. All the material, consisting of observation notes, reflections and memos was shared and discussed with the co-authors of the paper, my supervisors at the time.

In these initial analyses and discussions, we found that it would be worthwhile to corroborate or compare the observations from this single course with others, and thus I sought out and arranged to observe two other courses in the following semester, one aimed at bachelor physics students and the other at engineering physics students. The collection of materials proceeded in the same way in these courses, with observations of lectures and problem solving sessions, and a group interview conducted with a few students in each course. See Table 5.1 for a summary of the collected materials.

Table 5.1. *Number of observed classes, informal interviews, and number of participants in the group interviews conducted for project 2.*

Course	Lectures	Tutorials	Informal interviews	Interview participants
1	8/18	6/24	4	5
2	5/16	4/15	1	3
3	4/19	2/40	0	5

5.2.2 Analysis

When analysing the field notes collected in project 2, I started out while compiling the notes, by annotating them with "open" codes to begin to engage with the data. These codes ranged from just indexing types of activities or descriptions or who talks to whom ("place description", "students write", "students oppose something", "laughter", "student to teacher") to hint at more analytical perspectives ("performing as a good student", "this is how quantum mechanics is" etc.). These compiled notes were shared and discussed with my co-authors and in this process, the discourse analytical perspective of "building tasks" of discourse were found to be a useful analytical focus (Gee, 2011). In particular the analysis focused on the *practices* and related *positions* that were constructed in the discourse of the courses. In revising the research questions according to this, I reworked the coding scheme and added codes for particular constructions of practices and positionings. A final revision of the coding and a reworking of the material was done by collecting coded segments across different topics, and then sorting through these with an explicit lens of what practices and positions were constructed. For example, mentions of the history of physics were interpreted with a focus on how historical practices were constructed in relation to the practices of the courses. The interview material was mainly used as a contrast and "member checking" in this process, i.e. a way of getting students' perspectives on the courses. In writing the paper (Paper II), all these interpretations were discussed and refined among all authors. An in-depth example that follows the analysis from a single field note is given in Appendix C.

5.3 Project 3: negotiations of positions in master's studies

5.3.1 Data collection

The data for the last part of the doctoral project was collected using participant observation and interviews at two Scandinavian universities. The primary material used in the analysis for the included papers (IV and V) are the individual interviews but I will describe the full data collection process here.

This project aimed to explore how students make sense of becoming a physicist at the stage of starting on a master's programme, and what role specializations in physics subjects play. To achieve this, I devised a research design combining participant observation with in-depth individual interviews. I did the overwhelming part of the participant observation at one of the universities, being present for 4 weeks at the beginning of a semester on the physics master's programme. I participated in social activities such as guided tours of the campus and barbecue nights, and also went to classes in the various subjects taken by students at the different specializations of the programme. The observations were, whenever possible, documented with scribbled notes and collected into structured fieldnotes after each day of observation. Similar to the process for project 2, this writing out of the notes also involved an initial coding, reflection and memo writing. These observations gave me a good insight into the environment on the international master's programme, which served as a background for the discussions with the interviewed students.

Interviewees were recruited among the first-year master's students using a selection of methods. Some of the interviewees were asked to participate directly as I met them in the activities I participated in, others were reached through a facebook group. Four students were interviewed at the first university. At the second university, I could recruit interviewees with the help of the director of studies for the master's programme, where students were invited to write an initial "experience letter" which I followed up with an interview. Six students were interviewed at the second university. The aim was to reach a sample of students on different master's specializations and with different backgrounds. The final group of 10 interviewed students represents a significant variation in backgrounds (3 women, 7 men, coming from 8 different countries) and specializations. The national backgrounds of the students were Belgian (one), Chinese (one), German (one), Greek (two), Italian, (two), Mexican (one), Polish (one), and, Spanish (one). The specializations were: Biophysics (one), General experimental physics (one), Geophysics (one), Materials theory (one), Nuclear physics (one), Space physics (one), Theoretical physics (two), Materials physics (one), and Meteorology (one).

The interviews were semi-structured and focused on getting a broad picture of the students' experiences and negotiations as physicists-to-be but with specific questions about specializations, "identity", and quantum mechanics when applicable (see interview guide in Appendix B). Interview questions were developed to be mostly open, prompting students to explain their own experiences and to discuss views and values. In this way, the interviews represent a sample of discursive formations and an individual's negotiations of them. For example questions about study choice and follow up questions like "How do you think people view your kind of physics?" aimed at prompting a discussion and negotiation of perceived values. The interviews were recorded and transcribed.

5.3.2 Analysis

An initial phase of familiarizing myself with the interview material from the master's study was carried out by a first listening, indexing and open coding of the recorded interviews. I included a few questions about taking quantum mechanics classes in the interviews, and during the initial phase it became clear that quantum mechanics was a salient topic especially for some of the interviewees. The analysis then proceeded along two different lines for Paper IV and Paper V, with the subset of the interview material discussing experiences of taking quantum mechanics analysed for Paper IV. A detailed transcription of the interviews was made while developing themes for analysis.

Paper IV

For Paper IV, I analysed the parts of the interviews discussing quantum mechanics, aiming to understand how students made sense of an identity as physicists in relation to taking quantum mechanics. Only eight of the interviewees discussed quantum mechanics to a significant amount, so only these interviews were used for the analysis. Talk related to quantum mechanics was only a small part of the whole interview material but nevertheless contained rich narratives that could be analysed to outline a number of possible ways of relating to quantum mechanics. The analysis was done in a thematic way, based on a coding process with codes such as: "quantum mechanics as enticing", "quantum mechanics is difficult", "quantum mechanics is nerdy", "deeper understanding", "changed feelings". Relating to these themes, each student story was analysed focusing on negotiations of positions in relation to the quantum mechanics course. This analysis yielded common themes of expectations, attraction and difficulty (seen in all interviews), and two ways that students described they had responded to taking quantum mechanics (clearest for four of the students). Detailed examples from the data and analysis process are provided in Appendix D.

Paper V

For Paper V, I did a comprehensive analysis of the interviews with the master's students. Here too, I used a thematic approach in order to focus on the interviewees' negotiations of "imaginary positions" (Wetherell & Edley, 1999) in physics in relation to perceived discourses about physicists inside and outside the university. The thematic analysis was based on my initial open coding, where codes were used for "access" to discussions in the transcripts relevant for specific questions. For example, the code "physicist" linked all statements of how a physicist is, should be, or is perceived, with sub codes like "physicists vs engineers", "physicists are viewed as smart", "physicists are viewed as weird", "physicists are altruistic" pointing to various aspects that could be recognized in several discussions. Using these codes, thematic summaries were written to answer specific questions asked to the material such as: "in

what ways do the interviewees compare different kinds of physics and how do they position themselves in relation to them" or "how have the interviewees experienced the perceptions of others about physics students". These were collected into analysis drafts, which I discussed with my supervisors. With their feedback I could critically engage with the interpretations and ask questions such as: Is that a reasonable interpretation? Can it be argued to be prevalent in some sense, or is this a special case? After revising my interpretations based on these questions, I finalized drafts of the paper which were revised a few times after feedback from supervisors and colleagues. Detailed examples from the data and analysis process are provided in Appendix E.

6. Findings

This chapter summarizes the findings of the papers, that is, the answers to the research questions formulated in Section 1.2.

6.1 Paper I

The research questions for the project were:

I.1 How do students make sense of their experiences of the course in relation to gender, programme, etc.? What discourses are drawn upon? How is identity constructed?

I.2 Drawing on this analysis, can the gender gap be conceptualized or explained in more nuanced ways than "men perform better than women"?

For answering question I.1, the discursive constructions of course practice, significance and identities were analysed in the interviews. This showed how students made sense of their practice in the course in relation to the cultural messages the course gave and their identification with a specific study programme. In particular, there was a division between strategies of *studying to learn* and *studying to pass*. Students drew from discourses connecting their current studies to potential future occupations and current ideas about what it means to be a student of a certain subject. This means that, in programmes with more physics, the idea that detailed knowledge of electromagnetism should be part of one's professional identity lies close at hand. Thus, in general, the students on the Engineering Physics or Physics Bachelor programmes experienced a disciplinary significance of the course and described how they *studied to learn*. This was very different to the students on programmes containing less physics such as Environmental engineering, who often described how they failed to experience the course as significant for them and described a practice of *studying to pass* to a larger extent. With the students' descriptions of how they experienced the course, it was clear that electromagnetism was not experienced to be as significant for all students as it could be. We interpreted this as a culture meeting between a course situated in a strong physics context, and students enculturated in study cultures with different priorities and goals. Here, a kind of culture clash and misunderstanding occurred, leading to some students distancing themselves from the subject and therefore describing that they adopted a *studying to pass* strategy. An example of this distancing can be seen in this quote from an Environmental engineering

student: “Electromagnetism seemed narrower than I had expected. I couldn’t see the use of it in the fields I plan to work in.”

Students also drew from gender equality discourses, pointing out how the similar interests in each programme means that gender differences are less important. This was also partly confirmed in the analysis of the grade data, which showed how programme affiliation was more clearly connected to results than gender. The gender distribution of the programmes are very skewed (see Figure 6.1) and this largely explains the observed gender gap. There was only one statistically significant difference between men and women on the same programme (in Engineering physics). The conclusions to be drawn from this, which form an answer to question I.2, are that gender matters, but not necessarily on this specific level, where an identification with the programme and disciplinary concerns seem to have a greater effect on course performance. This paper was published in a collection of *PRPER* focusing on gender issues and in that context served as a case study illustrating how gender can come to matter on different levels in physics education. In particular, it contributes to a problematization of common “deficit models” where female students are understood as being deficient compared to men.

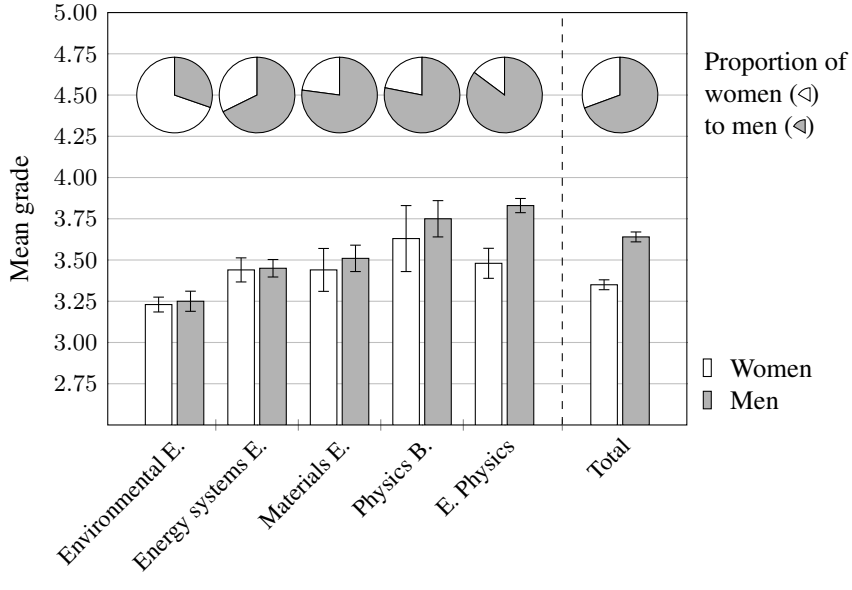

Figure 6.1. Mean grades for men and women on the five major programs on the course and for all students taken together. Error bars indicate standard error of the mean. Pie charts display gender distribution on the programme.

6.2 Paper II

The research questions for the project were:

II.1 What practices of doing physics and what discursive positions for enacting a legitimate or good quantum physics student are made available in the discourse of quantum physics courses?

II.2 How do these positions match students' expectations and what can they imply about wider physics practice?

In the analysis of the observations, three abstract practices were identified as being constructed in the discourse of the classes: *calculate*, *explore*, and *apply*, with *calculate* dominating. The dominance of the *calculate* practice means that instructor talk, tasks, schedules etc. together were found to make the practice expected of students be mainly about grasping the mathematical formulation of quantum mechanics and being able to apply it to many different examples. The practices *explore* and *apply*, hinting at for example interpretational issues or practical applications, appeared as secondary in courses. Practice is connected to identity (Gee, 2011, p. 30), and the analysis indicated that a discursive position as a good student in these courses meant adapting to and valuing the calculating regime, whilst not bothering with other aspects of the subject, that is, to "shut up and calculate". One answer to question II.2 is given by indications from the interviews, which showed that students anticipated quantum physics courses, thinking they would be very interesting, but could then experience the actual course as an anticlimax. This topic is developed further in Paper IV.

The primary implication of these results is that courses may be restrictive for students' identifications in physics. In this specific case, an intensive focus on *calculating* may preclude students imagining themselves doing quantum physics in any other way: conceptual, philosophical, applications, teaching etc., which are certainly relevant practices for many students. This also hints at how the local discourse in courses could also build up specific ideals of what it means to be a physicist. Putting these results into a larger picture, research on the development of quantum mechanics teaching points to how a calculating focus can be related to a specifically instrumentalist conception of physics, explicitly excluding philosophical discussions from the matters of concern in physics (Kaiser, 2002, 2007).

6.3 Paper III

Drawing from the insights of the first two papers, Paper III presents my approach to studying identity for the PER community. As discussed in Section 2.5 there are many ways of conceptualizing and studying identity in education. In PER, this has often been done in terms of individual students' iden-

tity development, for example by using a communities of practice approach. In this paper, I bring up the agency-structure dialectic to point to how common approaches risk missing issues of power, and how social structures may shape possibilities for identification. With examples from Papers I and II, I demonstrate how using a discourse perspective can be one way of asking and answering important questions about norms and power in physics education and thus getting a view of the interplay between agency and structure. There is a need for, and a growing interest in, looking at identity in physics education, and this paper points out how different approaches give different possibilities. In particular, if we want to address inequality, I claim that it is important to use approaches that allow us to talk both about the cultural features that may reproduce inequality and how students handle these.

6.4 Paper IV

The research question for this paper was:

IV.1 How have students' encounters with their first quantum mechanics course influenced their orientation and identification in physics?

In a sense, this paper is complementary to the analysis in Paper II, in that it turns the perspective around to look at students' experiences of quantum mechanics, rather than the discourse of quantum mechanics courses.

In the data, I could distinguish two approaches to quantum mechanics: accepting and withdrawing. These approaches were clearly represented by a few of the students, whose stories thus serve as cases illustrating possible ways of making sense of quantum mechanics studies. The stories of the other students, while not explicitly describing their approaches to taking quantum mechanics, contributed to the general picture of the importance of quantum mechanics. Some students had to re-evaluate their ideas about quantum mechanics and its place in their physics trajectories, thus withdrawing from the subject in one way or another. Others could more straightforwardly assimilate it into their idea of themselves and physics. The stories I have labelled as *withdrawing* point to initial great interest and expectations for quantum mechanics, which then transformed into an anticlimax as the course was experienced as less engaging and more difficult than expected. I argue that, on the one hand, traditional quantum mechanics teaching may be a part of making this experience of disillusionment so strong and life-changing. On the other hand, adopting some reformed quantum mechanics curricula and teaching approaches may be a way of capturing the interest of these generally successful students while at the same time helping students to reach a reasonable picture of what quantum mechanics is about. The paper is written for the readership of *EJP*, which means it aims to raise these questions for an audience of both physics instruct-

ors and physics education researchers, explicitly addressing the impacts different ways of teaching in quantum mechanics can have.

The results serve as an example of how students' meetings with local courses and discourses can entail drastic negotiations of identifications in physics.

6.5 Paper V

The research questions were:

V.1 What common discourses around being a physics or science person do the master's students draw on when narrating their experiences of physics studies?

V.2 How do the students negotiate their positions in physics in relation to discourses about ideal or stereotypical physicists and implicit evaluations of physics specializations?

The answers to the first question point to the deeper analysis of the second question. The interviewees in general refer to well-known stereotypes of physicists as intelligent but nerdy, and discuss how they have struggled to negotiate these stereotypes. In the analysis of the stories of their physics studies, it was clear that these stereotypes also came to matter for negotiations within physics studies, as they serve as more or less powerful "imaginary positions" that the students need to relate to. Importantly, in the narratives of the interviewees, the position of the intelligent but nerdy physicist was more associated to more pure and theoretical directions in physics, which in general were perceived to be accorded higher status. The interviewees negotiated being a legitimate physicists-to-be in relation to these positions, and this could mean resisting a tendency to be seen (and view oneself) as less worthy because of studying a less valued subject. An example of how this negotiation was done could be seen in Dan's affirmation of the students in his chosen specialization geophysics, as cool, ordinary and non-nerdy physicists, disassociating himself from the supposedly more nerdy theoretical physics students.

The study serves to illustrate how well-known norms and sterotypes can come to matter for students who are far along their path into physics. In particular, the exposition of how implicit status differences are negotiated around intelligence and nerdiness points to an area where physics education could contribute to a more equal environment for physics students by attending to and countering these norms.

7. Discussion

After this presentation of the findings of each of the papers, it is time to return to the overarching aims of the thesis. I have aimed to contribute to the understanding of diversity issues in physics, to introduce and develop critical identity perspectives grounded in discourse theory to PER, and to do this by asking how a successful physics student is formed and which subject positions are made available for students in the discourses of physics education. The results from the studies allow me to point to some partial answers to these very large questions. My goal is not to present a general result or theory that applies to all contexts where physics education takes place, but rather to provide exemplar cases from which researchers and practitioners can learn. In general, the studies have illuminated how positions as successful or normative physics students are constructed in various ways in several different contexts, but to demonstrate the contribution to the knowledge of diversity issues in physics made in this thesis, I want to highlight several themes raised by the findings that cut across the individual studies. This is the primary focus of Sections 7.1 to 7.4. In Section 7.5, I discuss how my results could be applicable for improving physics education. Furthermore, the work presented here contributes to the theoretical and methodological development of physics education research and the implications of this will be assessed and discussed in Section 7.6.

7.1 Study choice and identity

One issue that has become clear in the research presented in this thesis is how questions of study choice for students are deeply intertwined with questions about who they are and can be. The studies investigate these issues at several important steps on the path for physics students. From second year introductory physics (Electromagnetism) via "physicist defining" quantum mechanics to physics specializations in first year master's studies. Subject choice or programme choice is clearly defining at the undergraduate level where not everyone will become a physicist. For the interviewees in Paper I, the study programme largely defined who you were in the context and how you related to the Electromagnetism course. Some students disidentified with the "physics for physics sake"-attitude that they felt dominated the course and which some, perhaps more physics-oriented students, would be more inclined towards. Similar sentiments were given by some students in relation to the quantum mechanics courses in Paper II, where the question "what is in this for me" loomed

large for example for students in meteorology. A similar role is also played by the choices of physics subject specialization for master's students. Choosing to specialize in a specific subject means that your studies are viewed in a certain light, and is connected with higher or lower status. As described in Paper V, and also discussed in Paper IV, this could become an important issue in negotiating positions as a professional physicist. As others have pointed out before, study choice is very much a question that fruitfully can be investigated and understood using identity constructs (Holmegaard, 2015; Holmegaard et al., 2014), and this has been made even clearer when it comes to physics in my studies.

7.2 Intersecting identities in physics

One of the overarching findings from the studies reported in this thesis is that identification in physics is complex. While much earlier research has pointed to how gender, ethnicity, and social background intersects with physics identifications, my research points to the importance of the "fine structure" of physics culture for students' negotiations. Affiliations with different educational programmes can serve as one strong source of identification, and this also applies to different specialisations within physics. This is also tied to hierarchies and status within physics culture. However, this does not mean that identities such as gender are unimportant in physics. Rather, the gender distributions of the different educational programmes analysed in Paper I vary from women in minority to men in minority. The proportion of women and men also generally varies between the sub-disciplines of physics (Hasse, 2015; Hasse & Sinding, 2012; Hasse, Trentemøller & Bjerregaard Sinding, 2008). This means that the importance of study choice to identity is compounded with gender. For example, the lower status, more interdisciplinary, applied or experimental physics subjects discussed in Paper V often have higher (than the physics average) proportions of women. Even though the picture is complex and should not be oversimplified, this may indicate another type of "glass ceiling", or perhaps a "glass wall", where some subjects are still less open to students perceived as non-traditional in physics. As discussed in the next section, this may be connected to identifications with stereotypes and ideals of the intelligent abstractly thinking physicist.

The conclusions to be drawn from this are that we cannot consider physics culture or "physics identity" as singular, but must instead attend to the intersection of many discourses in defining possibilities for identifications in physics.

7.3 The formation of successful physics students – intelligence ideals

From the analyses of discourses and identities in physics, a few points about the normative position of the "successful physics student" can be extracted. The point here is that being successful in physics studies involves not only getting passing grades on the courses, but also performing an appropriate, intelligible identity. That is, conforming to the norms of physics education in some sense. I have pointed out how one way of conforming can be to adopt a "shut up and calculate" attitude in quantum physics, which could be compared to the "behavioural compliance" and "tick box learning" expected in school (Archer et al., 2017). Yet another norm or ideal in physics that is hinted at in all the papers is that of inherent intelligence, or even genius. Physics, as discussed in Paper V, is a subject where a certain type of "intelligence" is expected, and celebrated. In particular, in physics, compared to many other subjects, the idea of being a "genius" exists on the horizon of hopes and expectations. In her work about the culture of particle physicists, Traweek points to how these expectations and the realities of studying physics seldom add up. Traweek describes the stories told about becoming a physicist as a "romance of science", where the position as a genius, a textbook "scientist-hero", is what students should strive to become even though most will fail (Traweek, 1988, chapter 3). Some of my results have indicated that this ideal may still be prevalent in physics education. One example is given by the strivings of the students whom Sara in Paper V describes as "going Albert", who boldly and sometimes rudely assert their knowledge. This can be compared to performances of "muscular intellect" (Archer et al., 2017) or as stereotypical "smart superphysicists" (Gonsalves & Seiler, 2012). To some extent, the dream or ideal of wanting to become "the next Einstein", to make some big, ground-breaking discovery which may lead to a Nobel prize, circulates among physics students and physicists alike.

The greatest heroes of science are those who overturn "established paradigms", that is, who do "revolutionary science" (Kuhn, 1962/2012). This explains a part of the appeal of quantum mechanics, which has an undeniable place in this history. But most physicists will of course not be heroes. Rather, they will have to put up with what Kuhn, rather disparagingly, calls the "mopping up"-work of normal science (Kuhn, 1962/2012). If becoming a physicist in some way is conceptualized in the romantic fashion which Traweek describes, failing to become a hero of science and learning to be content with "mopping-up" may represent a position of resentment. This idolisation of physics heroes and idealisation of studying physics can be interpreted as one source of the troubles experienced by students in meeting quantum physics courses which are taught in a "shut up and calculate"-manner.

I have also pointed out how these ideal positions are gendered and traditionally associated with masculinity (Gonsalves & Seiler, 2012; Traweek, 1988).

Although the results from my studies do not mainly focus on how students relate to the gendering of these norms, many earlier studies suggest that this may be a major issue in building a diverse physics education. Together with my results, this indicates a problem where gendered stereotypes and ideals can create patterns of exclusion for minoritized students in physics.

7.4 Physics culture and imagined futures

One of the points of adopting the discourse perspectives used in this thesis is that it invites a discussion of the wider context that structures students' experiences. It allows me to lift the gaze slightly from the priorities and worldview of physics to also discuss what physics means for students and others and what it could mean. In what kind of physics culture are the discourses analysed in the studies situated, and what kind of culture is reproduced in the formation of successful physics students? In Paper II, a part of this question is discussed in terms of the seemingly instrumentalist approach to physics conveyed in the quantum mechanics courses. This instrumentalist approach may in the case of quantum physics be related to a Cold War orientation towards educating physics workers (aimed at military applications) rather than natural philosophers (Kaiser, 2002, 2007). Even if such a pragmatic or instrumentalist approach is generally what students encounter in physics courses, it cannot however be said that this ideal dominates how students think about physics. For some students, a large part of the attraction of physics lies in its promises of acquiring or discovering deep knowledge of the workings of the universe, a (perhaps vain) hope that risks leaving many students disillusioned by the education they encounter. An opposition is created between physics imagined as exciting and deep, and physics practised in a dry, formal or instrumental sense. On the other hand, for the non-physics programme students in Paper I, physics appeared primarily as narrow and dry, similar to the bad reputation it sometimes has in school. In both cases, physics fails to make itself worthwhile with respect to these students' goals. In this sense, physics education can at times seem irrelevant for both students taking physics motivated by a strong commitment to the subject itself (as is clear in Paper IV) and students who need physics but do not study it for its own sake (as in Paper I).

All this raises questions of who physics is for, and what we can imagine physics to be. Hasse (2015), in drawing from her fieldwork on a physics programme, discusses how a fondness for hard sci-fi and narratives of space exploration among physics students and teachers may result in a skewing of "future imaginaries" related to science. That is, the conceptions of what physics is "for" may be aligned more with "male fantasies" of exploration and conquest, than with for example visions of improving the environment or peoples' health. Colonising Mars becomes more important than solving the energy or climate crises (see also Hansson & Lindahl, 2007). This may also estrange people not

aligned with this vision for physics. In my studies, I have not chosen to look for these "future imaginaries" in particular, but it is helpful to consider the findings in light of these questions. My findings do point to various "dreams" about physics, for example as something which will be able to provide grand insights and as something much more mundane or boring. Perhaps the question is whether any of these ideas of what physics is really match what physics educators would like it to be. In Paper V, one of the interviewees, Eugenia, describes her reason for studying physics as wanting to develop materials for solving the world's energy problems. In one way a grand goal, but in another way much more "down-to-earth" than both exploring Mars or understanding the universe. Furthermore, motivations such as Eugenia's for studying physics do not seem to be normative or common. Today's physics students are more "physics for physics sake"-oriented (Levrini et al., 2017). The questions this raises are whether it is possible to imagine a physics education that is more open to various ideas and ideals of the purpose of physics, and whether the formation of successful physics students would then look different. In the end, it also comes down to what role physics and physicists will play in meeting future challenges such as environmental protection and energy supply. Should physicists be expected only to have their heads in the clouds (or among the stars) or should physics strive to also be open to more varied and down-to-earth concerns?

7.5 What can be done?

While the research in this thesis is exploratory and does not generally aim at providing ready solutions for implementation, a few suggestions for the improvement of physics education can be made. In general, what anyone involved in physics education can hopefully take away from this work is increased knowledge or understanding of the situation of physics students. The studies have provided several cases of how physics education can be experienced by students, and it is my hope that knowledge about these perspectives may serve as a valuable background to any reformation of physics courses and curricula. In particular, the increased awareness of the sociocultural and identity aspects of physics education provided by my work can be brought into reform work.

There are also some more specific recommendations to make. First, the results from the investigation in Paper I, which was motivated by the concerns of physics instructors, have already led to a reformation of the Electromagnetism course in an attempt to make it more relevant for the diverse student groups attending it. In particular, the course has since included more connections to applications in the fields of the students and now invites guest lecturers from these fields. A perhaps obvious, but nevertheless necessary, lesson to take away from this is that we need to be aware of the background, possible futures,

and current needs of the students in our courses. This does not only apply to the majority, i.e. knowing and adapting to the major study programmes taking a course, but also to the diversity of students in physics.

Two questions that should be asked in this context are what the possible motivations for students taking a course are and how these motivations can be employed for getting students engaged. I discuss these issues in relation to the possible mismatch between expectations and experiences of quantum mechanics documented in Papers II and IV and suggest implementing curricula with an increased focus on interpretation and applications in Paper IV. This kind of change could be viewed as adapting to popular demand and providing "dumbed-down" physics courses, but I do believe that taking a step back and evaluating what we give students and why generally leads in the direction of providing more context to the topics brought up in class. Again, I think there is a need for considering what kind of visions we want to enable, for the students and for physics. For example, a quantum mechanics course could surely have room both for thinking about solving global problems of energy supply and storage and alternative ideas of what happens when we measure a quantum particle. Maybe a part of this openness lies in bringing in perspectives beyond the immediate priorities of the discipline of physics, which may of course be a difficult task for anyone trained primarily in physics.

Another issue that becomes especially evident in Paper V is the propagation of certain ideals and stereotypes of physics people that can occur in physics education. To the extent that these ideals may in unjustified ways disfavour certain people or encourage certain identity performances in physics, measures to counter them should be taken by physics educators. The idealized positions discussed in Paper V are that of the intelligent, absorbed and even nerdy physicist focused on solving deep theoretical questions. One way of countering the reproduction of such social ideals may again be to make a variety of concerns and ways of relating to physics content more available in physics, for example by discussing related and interdisciplinary subjects. There may also be ways of actively addressing problematic expectations. A good example that did not make it into any of the papers, is given by one of the lecturers in the quantum mechanics classes observed for Paper II. After having written an expression on the blackboard, this lecturer asked the students how the written sum should be calculated, pointing out that the students should have learned this in their first mathematics course. The lecturer then waited for a while before announcing that "this is an arithmetic sum, I had to look it up". This made the classroom burst out in laughter, and I take this as an indication that the lecturer by this simple gesture of honestly admitting ignorance dispelled some of the tension around appearing intelligent in the physics classroom.

As a critical scholar, I have attempted to question taken-for-granted truths about physics education and in doing so provide more ideas and questions for work towards a more diverse physics education. More research about these issues is certainly called for, but the results and suggestions presented here

do provide important starting points both for developing physics education in practice and investigating it further.

7.6 Using critical discourse perspectives in PER

The aim of this thesis is not only empirical, but also theoretical and methodological. I have brought perspectives on identity from a poststructuralist tradition into physics education research, and in doing so have shown how these perspectives allow new insights about the social nature of physics education to be reached. How has this approach allowed these insights and how can it be valuable to others?

One of the points that I have emphasized is that the poststructuralist account of identity as constructed in discourse implies an emphasis on both structure and agency. Here, the imposition of structural restraints takes its form through the social institution of certain relations, facts and identities in discourse, which direct how we make sense of the world. In negotiating this structure, there is however also room for agency. With this perspective, I have shown how it is possible to discuss identity beyond a focus on students' development in relation to established structures (too strong agency focus) and instead also discuss the reproduction of these structures.

The quantum mechanics project (Paper II) serves as a good example for illustrating these points. The typical physics education research questions asked about a class in quantum mechanics would concern the subject knowledge of students, or how they could learn to be "good" quantum mechanics students in terms of "thinking like a physicist". However, taking an identity perspective meant that I instead focused on the social issues of this particular physics subject, something which has not been done to any large extent before. Furthermore, with a discourse perspective, the question of identities is raised beyond asking how a student can feel at home in quantum mechanics to also include questions of what the consequences of the specific make-up of this "home" is for students. An increased attention is paid to the conditions for student identifications. Apart from this, the idea of the radical contingency of discourse provides an incentive to ask how things could be otherwise. In the case of Paper II, I ask what a "good" quantum mechanics student is in terms of identity, dispositions, and practices, but also raise the question of what kind of physics this student then is "good" at. Here, the discursive construction of a dominant kind of physics practice (calculating) with an appropriate student position (calculator) is highlighted and brought up for discussion. Could it be otherwise? That is, could another kind of ideal student be formed in these courses? Who is served by the quantum mechanics course focusing almost exclusively on calculating, sometimes to the detriment of conceptual understanding but also marginalising contextual topics such as history, applications, epistemology etc.? In Paper II it is suggested that this matches the priorities of

students planning to do theoretical physics better than others. It is the critical research approach embedded in discourse studies that enables these important questions of power to be asked in my work.

Naturally, the approaches I have taken in this thesis have their limitations. A qualitative investigation cannot claim to cover an extensive breadth of samples, but rather in contrast aims to provide in-depth understanding of the investigated cases. The qualitative analyses of discourse presented in this thesis provide this kind of in-depth understanding of certain cases. They give an understanding that cannot be easily generalised and seen as applying to physics education everywhere, but that nevertheless gives pieces to the puzzle of understanding diversity issues in physics education. In particular, the cases analysed in this thesis provide opportunities for learning how things *can* and, in these particular cases, *do* work out in physics education.

There are several lines of inquiry that would be worthwhile ways of continuing the research presented here. For example, taking the perspective of the different levels of university physics education further, a more longitudinal research project could highlight students' negotiations throughout physics studies. In my view, this research should still avoid focusing too heavily on students' identity development, and make sure to put development in context and ask questions such as: What physics context is encountered by the students? What discursive constructions do students have to relate to and reproduce? Why is this so? Furthermore, the in-depth look at discourse and identities in particular contexts of physics education (such as specific courses) presented here point to the possibility of using the perspective of intelligible positions in discourse in additional contexts beyond the reach of this thesis. In particular, how do students' negotiate positions as physics people when encountering what is at times considered "boring" introductory courses such as mechanics? What happens in "exciting" relativity classes? A further look at the discourses in the classrooms and labs of graduate studies would also be enlightening.

The specific findings of the papers also point to further questions that would be interesting to answer in the quest for understanding the social environment of physics education better. For example, the topics of intelligence and nerdiness do seem to come up in physics in various ways, but there are also important variations. For example, the emphasis on nerd culture, sci-fi, and exploring space described by Hasse (2015) was not as apparent in my studies. How do these variations of common themes arise? What intersections between physics culture, national culture, gender, ethnicity, etc. can be seen, and how do these intersections affect potential physics students?

In summary, the work presented here gives some answers to social questions about how successful physics students are formed, but also raises many new issues that need to be developed for a more diverse physics education.

8. Contributions and implications

The aim of this thesis is to contribute to knowledge about diversity in physics education by developing perspectives on identity in physics education research. My main contributions to the PER literature lie in showing the feasibility and value of using discourse and identity perspectives for analysing physics education, in specific physics contexts. In particular, I show how identity can be used to characterize the actualization of cultural norms in physics that are not only about commonly discussed group identities (gender, class, ethnicity), but also about specific cultural features of physics. That is, a critical investigation of "physics identity". I have done this through case studies showing how cultural norms in physics can come to matter for students, adding pieces to the puzzle of diversity and social issues in physics.

8.1 Contributions to knowledge about diversity issues in physics education

The primary aim of this thesis stems from concerns about diversity and the sociocultural aspects of physics education, such as underrepresentation of women and minorities. My work contributes to and expands the tradition of researching these issues with an identity perspective. In this context, the particular empirical contributions from my studies are:

- *That students relate to physics courses very differently and that negotiating the practice of taking physics courses is related to identity*. This is evidenced by the students on various engineering and physics programmes in Paper I, but also by the physics students with diverse backgrounds and interests taking quantum mechanics in Papers II and IV.
- *That courses can limit student negotiations of identity and practice, sometimes in less than ideal ways for both the interest of students and the physics community*. The results in Paper I, point to this conclusion which is then further substantiated in Papers II and IV. In particular, the calculating practice of quantum mechanics courses is highlighted as an example of this limiting of available positions.
- *That courses in quantum mechanics hold a special significance for physics students, that the reality of the courses may not meet students expectations, and that the investments students have in the subject may necessitate a distressing renegotiation of their place in physics when they encounter the course*. This is the main result in Paper IV.

- *That quantum mechanics courses are thus important for the future trajectories of students within physics*.
- *That questions of study choice in physics are fraught with issues of identity, sometimes concerning status and stereotypical attributions*. In Paper I, students on various study programmes taking physics indicated that identifying as, for example, an environmental engineering student was different from being a physics programme student, and implied different mindsets and approaches to studying. In Paper V, this picture was expanded by looking at physics master's students.
- *That norms about intelligence and nerdiness can be central axes around which students negotiate their position in physics, and that this is related to study choice in that theoretical and pure physics is viewed as requiring more intelligence*. This is the primary result of Paper V.
- *That identity questions in physics are complex and imply an intersection of many categories*. For example, gender appears in different ways and on different levels in students' identifications. Paper I showed that a gender gap in results rather stemmed from a gender gap in study choice on a wider societal level. Paper V shows how gender and social background can intersect with study choice in students' evaluations of status, and with their feelings of authenticity as physics students.

8.2 Methodological and theoretical contributions to PER

A further aim of the project is to continue to expand the methodological and theoretical horizon of PER. By engaging with theories and methodologies from gender studies and critical studies of science education I have pointed to how:

- *An identity perspective informed by a poststructuralist notion of discourse can be a viable approach in PER*. These theories have been used to a limited extent in PER before, but have been suggested as one way forward to get deeper insights in gender issues etc. (Traxler et al., 2016).
- *An identity perspective can give more nuanced views of students' performance in physics and thus challenge deficit models explaining the underperformance of certain groups of students*. Here the findings in Paper I for example clearly demonstrate how adopting an identity perspective can lead to a different interpretation of what appeared to be a gender bias problem in an undergraduate physics course.
- *Participant observation and qualitative interviewing are feasible within PER as ways of collecting instances of enacted discourse.*
- *Interpretative, qualitative analysis is a valuable way of analysing this kind of discursive material.*

- *These tools and theories allow the researcher to put a focus on the interactions between agency and structure and to discuss power in terms of norms.*
- *Using these tools and theories means refocusing the analysis from individual students' navigation through the university system to how discourses in physics education can structure the possibilities for identification, and how students negotiate these possibilities.*
- *A focus on local discourses in physics education and how they draw from wider discourses embedded in a more or less global physics culture allows a detailed view of how identities are constituted in physics.*
- *An approach to physics education that takes departure in social critique allows a rethinking of taken-for-granted values of physics education.* That is, aiding researchers and practitioners in reflecting upon why things are as they are and whether they need to be that way.

8.3 Implications for physics educators

For physics educators at the university level, the studies reported in this thesis have pointed to the importance of paying attention to students' identifications and other social and affective aspects of physics education. Some particular recommendations for the contexts I have studied are given below:

- *For electromagnetism*, the inclusion of more applications and examples connected to a student's specific educational programme can lead to increased engagement. After being informed of the findings of Paper I, instructors on the Electromagnetism course took these measures with successful results.
- *In quantum mechanics*, it is important to pay attention to students' motivations and interests. This can involve acknowledging various common expectations and everyday ideas about quantum mechanics, and discussing how the course will or will not address them.
- In addition, *for quantum mechanics*, previously developed curricula for engaging further with for example interpretational issues may be one way of widening the appeal of the course to more students, i.e. matching expectations and making the best of students' enthusiasm.
- *Regarding physics education in general*, my work highlights the importance of working to counter stereotypical attributions about physics or physicists such as intelligence and/or nerdiness. In particular, it is important to be aware of potentially differing stereotypes about certain fields of physics and their practitioners and to counter the effects this may have on students' negotiations of self-worth, identity, and study choice.

- *For improving physics education in general*, my work points to how focusing on the influence of culture, discourse and institutions can provide important tools for instituting change. For a more diverse physics culture, the focus cannot be on changing students, but on changing educational programmes, courses and cultural values in physics.

9. Concluding remarks

Having finished my doctoral work, I have gotten closer to answering some of the questions that motivated me to start on this project. My research has shed some light on the seldom asked question of what it means to become a physicist, the question that I and my fellow physics students struggled with already when we were in our first years of the physics programme. The work in this thesis does not only resonate with my personal quest for understanding, it also provides knowledge and new questions for others. I cannot promise so many simple answers however. As a form of critical research, I do hope that my work has made it less easy to take how physics education works and should work for granted.

My primary contribution to the physics education research field is theoretical and methodological. By combining theoretical discourse perspectives developed and used in other fields with an in-depth focus on physics subjects and students' particular experiences, I have shown a way forward for a better understanding of the identity issues in physics education. The results of my individual studies already give some input to reforming physics teaching in a more inclusive way, but further research and reflection is needed for creating a diverse physics. Importantly, I have not touched upon the issue of recruitment in this thesis, except by noting the unequal representation of women and men in physics education. As the work of others shows, physics is often positioned as masculine, dry, or boring already in school, something which supposedly turns women away at that early stage. Much work is needed across the educational system, and in public perception, to make physics an appealing subject to as wide a group of people as possible. In my opinion, a critical research programme using discourse or similar constructs is well-equipped to understand how these issues play out and how power relations in society are mirrored in physics. This approach has largely been missing from PER, and my work is one more step on the path of bringing it in.

Sammanfattning på svenska

I den här avhandlingen undersöker jag sociala aspekter av fysikutbildning på universitetet. Med hjälp av ett kritiskt perspektiv på normer och identiteter har jag undersökt hur utbildningen kan definiera ramarna för vem som kan känna sig hemma som fysiker. Fysik är ett ämne som fortfarande är ojämställt, och målet med forskningen är att bidra till att öppna möjligheter för en bredare och mer inkluderande fysik. Jag vill göra detta genom att stimulera till diskussion både bland institutioner och universitetslärare och inom mitt forskningsfält fysikdidaktik.

Forskning inom fysikdidaktik (på engelska Physics Education Research) har under de senaste årtiondena bidragit till välgrundad kunskap om hur studenter lär sig fysik och vilken typ av undervisning som bäst uppmuntrar lärande. Däremot har denna forskning i begränsad utsträckning undersökt sociala frågor kring jämställdhet och mångfald i fysikutbildningen. Fysik har liksom alla universitetsämnen traditionellt dominerats av män och även om kvinnor idag utgör en majoritet av studenterna på svenska universitet i sin helhet, är könsfördelningen fortfarande mycket skev inom fysiken. Redan på grundutbildningarna i fysik är det bara omkring 25% kvinnor. Förutom att det kan ses som en enkel fråga om rättvisa brukar målet att höja representationen av kvinnor inom fysik och annan teknik och naturvetenskap lyftas som ett sätt att åtgärda den ofta diskuterade bristen på utbildade naturvetare i västvärlden. Här har forskning om rekrytering, studieavhopp och genomströmning pekat på att det hela är ett komplext problem, där miljön på universitetets institutioner samverkar med den bakgrund och de förväntningar som studenter tar med sig till sin utbildning. Ett exempel från forskningen är en tendens hos studenter i fysik att tillskriva ett eventuellt ”misslyckande” med att slutföra sin fysikutbildning enbart till sig själva. De anser sig inte ha varit ”tillräckligt bra”. Detta kan vara en indikation på en prestationsinriktad miljö där studenters studieframgång uppfattas definiera deras värde.

Forskning om fysiklärande har också pekat på att det kan finnas skillnader i hur väl kvinnor och män presterar i examinationer och standardiserade tester som undersöker konceptuell förståelse av fysiken. En del av förklaringarna till detta har sökts i psykologiska mekanismer som att minoritetsgrupper kan uppleva sin kompetens som lägre än majoritetens, vilket ibland har visats gälla för kvinnor inom fysiken. Förutom jämställdhet mellan kvinnor och män har en del forskning också visat hur grupper som redan är underrepresenterade på universitet också missgynnas inom fysikämnet. En ytterligare aspekt av ojämställdheten inom fysiken är den att andelen kvinnor minskar ju högre upp

i universitetshierarkin man kommer, ett problem som är välkänt inom resten av akademin och yrkeslivet och ibland beskrivs som att kvinnor stöter på ett ”glastak” när de försöker avancera uppåt på karriärsstegar.

Jämställdhets- och mångfaldsproblem har inom utbildningsforskning i allmänhet undersökts med metoder och teorier som framhäver vikten av sociala interaktioner, normer och identitetsskapande. Inom fysikdidaktiken har denna inriktning påbörjats, men det finns ett behov av mer kunskap och en utveckling av angreppssätten. Mitt arbete syftar till att bredda kunskapen om de sociokulturella aspekterna av fysikutbildning. Jag fokuserar specifikt på att undersöka vad det betyder att lära sig fysik och att bli fysiker. Vilka sociala identiteter konstrueras som legitima och begripliga under utbildningen? Vad utesluts? Istället för att bara utvärdera ”framgång” i fysiken som studenters lärande och prestation på examinationer vill jag undersöka hur idén om den framgångsrika fysikstudenten formas. Vilka implicita normer ligger i att vara framgångsrik inom fysiken?

Utveckling av fysikdidaktiken

Mitt forskningsområde, fysikdidaktik, har traditionellt varit nära knutet till fysikinstitutioner. Forskarna i ämnet har oftast en bakgrund inom fysik och har undersökt hur studenter lär sig olika aspekter av universitetsfysik. Att avdelningar för fysikdidaktik har varit placerade på fysikinstitutioner har inneburit många fördelar då kontakten med ämnet och undervisande universitetslärare varit nära och möjligheterna att påverka och förbättra fysikundervisningen varit goda. Detta har gjort att man har kunnat göra stora framsteg i kunskapen om studenters lärande i fysik och i implementeringen av effektiva undervisningsmetoder. I denna tradition har i första hand fysikinnehållet i undervisningen varit i fokus, vilket har medfört att helhetsbilden av utbildningen sällan belysts. De teorier och metoder som har använts inom fältet har då också främst riktats mot det kognitiva, studenters tänkande kring fysik, och inte i någon större utsträckning mot det sociala eller socialpsykologiska, studenters tänkande kring att bli fysiker. Mitt arbete syftar därför till att utöka de metodologiska verktygen inom fältet genom att tillföra teorier och metoder som är väl ägnade till att undersöka sociala normer. Jag använder ett perspektiv som är vanligt inom den genusvetenskapliga traditionen: att se identitet som diskursivt konstruerad. I denna tradition framhålls hur vår sociala identitet konstrueras just socialt, genom tal, skrift och andra betydelseskapande praktiker (d.v.s. diskurser). Å ena sidan formas hur vi uppfattar oss själva och andra utifrån redan givna kategorier och tankemönster, till exempel idéer om hur en fysiker ser ut och uppför sig. Å andra sidan kan dessa mönster också ändras genom förskjutningar och omtolkningar av vedertagna ”sanningar”. Att visa hur dessa perspektiv kan bidra till ett bättre förståelse för social identitet och normer inom fysikdidaktiken är en central del av mitt projekt.

Vad har jag gjort?

För att undersöka sociala aspekter av fysikutbildning på universitetet har jag under doktorandtiden genomfört tre olika studier, som resulterat i fem artiklar. De metoder som jag har använt har framförallt varit sådana som är vanliga inom samhällsvetenskap och humaniora, men som har varit mindre vanliga inom fysikdidaktik. Med hjälp av öppna, kvalitativa intervjuer, både med enskilda studenter och i grupp, har jag undersökt hur studenter har erfarit, och relaterat till, sin utbildning. I varje intervju har studenternas berättelser fått ta plats och jag har sedan tolkat dessa i jämförelse med övriga intervjuer. Jag har också gjort direkta, deltagande observationer av vad som sägs och händer på föreläsningar och lektioner i fysik. Till skillnad från mer konventionell fysikforskning, syftar inte denna typ av forskning till att producera statistiska samband eller lagar, utan till att bidra till förståelsen av den sociala världen. Då forskningen är kvalitativ och tolkande blir resultaten tolkningar av hur normer och identiteter kan skapas på de fysikutbildningar jag har undersökt. I samklang med tidigare forskningsresultat kan dessa tolkningar ge ytterligare pusselbitar i vår förståelse av normer och sociala interaktioner inom fysikutbildningen.

Vad har jag kommit fram till?

Elektromagnetism och genus på flera nivåer

I det första projektet, som presenteras i artikel I, undersökte Staffan Andersson och jag vad som av lärarna på kursen i elektromagnetism vid Uppsala universitet uppfattades som en tydlig könsskillnad i examinationsresultat. Elektromagnetism är en grundläggande kurs i fysik som läses av flera ingenjörsprogram och kandidatprogrammet i fysik under utbildningens tidiga år. Genom intervjuer med studenter som just avslutat kursen kunde vi peka på hur studenternas prestationer främst verkade bero på hur de identifierade sig. Är jag en sådan som ”älskar Maxwells ekvationer bara för att de finns där” var, som en av studenterna uttryckte det, en implicit fråga som kunde avgöra hur mycket energi en student lägger på kursen. Identifikationerna visade sig dock enligt studenterna handla mycket mer om programval och intresse än kön, och i en fördjupad statistisk analys kunde vi peka på hur det för det mesta inte fanns någon statistiskt signifikant skillnad i resultaten för kvinnor och män inom de studieprogram där kursen ingår. Å andra sidan är det en övervikt av manliga studenter på de program som ”ligger närmast” fysiken och där studenterna fick högst resultat på kursen, som Teknisk fysik och Kandidatprogram i fysik, och en övervikt av kvinnor på det program där resultaten var lägst, Miljö- och vattenteknik. Slutsatsen är att detta främst är en fråga om genus på en övergripande nivå. Det handlar om vilka ämnen som anses attraktiva och intressanta för kvinnor respektive män, men rör sig inte på en individuell nivå. Kvinnliga

och manliga studenter med liknande intressen och förutsättningar presterar i stort sett lika bra.

Kvantmekanikkurser – centrala men snäva?

I det andra projektet, som presenteras i artikel II, fokuserade jag på den första kursen i kvantmekanik. I Sverige och många andra delar av världen läser de flesta studenter på fysikinriktade program en introducerande kvantmekanikkurs under det andra eller tredje året av utbildningen. Att ha läst denna kurs kan sägas definiera studierna som fördjupade inom fysik; färre läser kvantmekanik jämfört med till exempel elektromagnetism. Jag observerade undervisningen och intervjuade studenter under tre olika kvantmekanikkurser på två olika universitet. Jag kunde notera att studenterna ofta såg kursen som något speciellt, kanske rentav som ”den roligaste kursen på hela utbildningen” efter vilken det ”bara kommer gå utför”, som en student skämtsamt sade till sin kamrat före den första föreläsningen. Det jag tillsammans med mina medförfattare fann i analysen av observationsmaterialet var att kurserna i praktiken sällan skiljde sig från de flesta andra fysikkurser. I förhållande till studenternas (ibland väl högt ställda) förväntningar så presenterades kvantmekaniken här som ytterligare ett matematiskt ramverk att lära sig hantera. En av lärarna meddelade detta tydligt i början av kursen och uppmanade studenterna: ”Räkna, räkna, räkna. För att förstå kvantmekanik måste ni räkna.” Saker som tillämpningar eller de filosofiska svårigheter som kvantmekaniken kan erbjuda, och som fysikstudenter ofta intresserar sig för, lyftes fram i mycket mindre utsträckning. Analysen av denna situation pekar på hur kurserna bidrar till konstruktionen av en framgångsrik fysikstudent som en som ”håller tyst och räknar”, som tar till sig det teoretiska matematiska stoffet och hantverket men inte ställer så många andra frågor. Denna roll utesluter lätt från början de studenter som läser kursen för andra syften än att i framtiden framförallt göra teoretiska kvantmekanikberäkningar, såsom lärarstudenter eller meteorologistudenter. Förutom detta kan en snäv bild av hur en framgångsrik fysikstudent ska vara göra att de som har mycket investerat i kvantmekaniken antingen anpassar sig till detta eller behöver omförhandla sin fysikidentitet.

Även i den del av det tredje projektet som presenteras i artikel IV, fokuserade jag på kvantmekanik. I detta projekt intervjuade jag studenter från en rad olika länder som just påbörjat sin masterutbildning i fysik. Alla hade läst en första kvantmekanikkurs under sin kandidatutbildning och för vissa studenter hade kvantmekaniken spelat en avgörande roll. För dessa studenter var kvantmekanik ett av de ämnen inom fysiken som var särskilt lockande, men när de vid intervjutillfället såg tillbaka på sina erfarenheter av kursen och sina val efter detta var de inte odelat positiva. I analysen av alla berättelser om erfarenheterna av kvantmekanik kunde jag se att vissa studenter utan problem kunde acceptera och ta till sig det förhållningssätt till kvantmekaniken som kursen

erbjöd. De upplevde inte någon friktion i att identifiera sig som framgångsrika fysikstudenter med kvantmekaniken som en självklar del av sin kompetens. För de studenter som haft höga förväntningar men också svårigheter i kursen, kunde jag istället urskilja ett avståndstagande från ämnet. De kunde inte längre se sig själva som den typ av fysikstudenter som självklart och självsäkert hanterar kvantmekaniken och behövde också förhandla sin position som fysiker då de uppfattade att kvantmekanik gav högre status än deras nuvarande ämne. Alla de intervjuade studenterna klarade kursen och tog sin examen, men erfarenheterna hos vissa ledde ändå till att de kände att det inte var ett ämne ”för dem”.

Sammanfattningsvis pekar detta på att kvantmekanikundervisningen kan behöva vara mer lyhörd för studenters förväntningar och idéer kring ämnet. Detta kan innebära att bredda innehållet i kurserna till att innefatta mer av tolkning, filosofi och tillämpningar, men betyder inte att kärnan i den matematiska formuleringen av kvantmekaniken ska överges.

Masterstudenters förhandlingar kring bilden av fysikern

I det tredje projektet ville jag flytta fokus ytterligare en bit längs vägen mot att bli fysiker och fokuserade därför på masterutbildningen. De intervjuade studenterna hade just börjat på masterprogrammet och syftet med den undersökning som presenteras i artikel V, var att undersöka hur studenterna förhandlade sin roll som blivande fysiker i förhållande till vad de uppfattade som normativa och förväntade sätt att vara fysiker. Här såg jag att ämnesval har stor betydelse. Som tidigare nämnts verkade kvantmekanik, men även mer teoretiska eller grundläggande fysikämnen överhuvudtaget, tillskrivas en hög status. Detta verkar röra sig om normer kring intelligens inom fysiken. Vissa ämnen ses som lite ”smartare” och därmed ”bättre”, medan andra ämnen ibland ses som att de bara är för de som inte var smarta nog. En av informanterna, som läste på inriktningen i meteorologi, förklarade hur han ibland presenterade sitt studieämne som ”atmosfärisk fysik” för att folk inte ska se honom som en typisk TV-meteorolog som ”bara” berättar om morgondagens väder.

Normer kring intelligens i fysiken anknyter till en könad stereotyp eller idealbild av fysikern som ett världsfrånvänt geni (”Einstein”, eller för den delen Seldon Cooper ur TV-serien *The Big Bang Theory*). Denna bild pekar dock även på fysikern som ”nördig”, och detta visade sig också spela roll för de intervjuade masterstudenterna. En av studenterna som läste geofysik förklarade hur han och hans studiekamrater var mer ”normala människor” som ”går på fester och så” jämfört med en del antaget mer nördiga studenter på den teoretiska inriktningen. Jag tolkar detta som ett sätt att göra motstånd mot bilden att vissa sorters fysik och fysiker skulle vara sämre.

Vad betyder detta för fysikundervisning och forskning i fysikdidaktik?

Mitt avhandlingsarbete bidrar till en fördjupad bild av sociala förhandlingar kring identiteter och normer i fysikutbildningen. Resultaten och den metodologiska utvecklingen i avhandlingen tjänar som en utgångspunkt för vidare forskning kring identitet inom fysikdidaktiken. Mer specifikt ger de perspektiv jag använder större möjligheter att analysera identitetsskapande i termer av normer och maktrelationer. I artikel III, som presenterades vid den årliga amerikanska fysikdidaktikkonferensen, diskuterade jag hur dessa perspektiv kan bidra till en bättre förståelse för social identitet och normer inom fysikdidaktiken. Resultaten av mina studier pekar på att vi behöver vara försiktiga när vi utvärderar genusfrågor i fysikutbildning. Ibland visar sig studieämnet spela mycket större roll än kön, men det finns då ofta redan från början en ojämn könsfördelning grundad i vilka ämnen som anses som mer manliga eller kvinnliga. Detta ser vi i yrkeslivet i allmänhet, när det gäller ämnesval inom tekniska och naturvetenskapliga ämnen, och dessutom också för de olika delarna av fysiken. Min forskning visar också hur valet av undervisningsmetoder och innehåll kan ge signaler till studenterna om vem de bör vara för att vara en framgångsrik fysikstudent. För att möjliggöra en bred och inkluderande fysikutbildning behöver hänsyn tas till vilka signaler som olika metoder och innehåll ger, och då är det viktigt att fundera på från vems perspektiv en specifik kurs ges. Ytterligare ett resultat av min forskning är hur stereotypa normer om intelligens och ”nördighet” inom fysiken kan spela roll för fysikstudenter. Som resultaten av artikel V indikerar är detta inte bara abstrakta stereotyper om ”fysikern i allmänhet” utan de har också betydelse för fysikstudenters ämnesval, uppfattning och värdering av sig själva i en implicit statushierarki bland fysiker. Att vara medveten om dessa värderingar och motverka dem i undervisning och information är ett sätt för fysikinstitutioner att verka för en mer öppen och inkluderande fysikutbildning.

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Appendix A.
Information letter for students interviewed in project 3

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Participation in an interview regarding experiences of starting on a Master's programme

This is an information letter and a consent form where you will get information about what it means to participate in the study and how your personal information will be treated during the research process. It is important that you read this information carefully before giving your consent to participate in the study and starting the interview.

Your given consent means that you accept to 1) participate in an interview which takes around an hour. The interview will be about your experiences and thoughts about studying physics, 2) have the interview recorded (except if you don't want to, then I will take notes instead), and 3) let the material from the interview be used for research purposes as described below.

Before you agree to participate I ask you to make sure that you have understood the purpose of the study and interview and that you have gotten sufficient information about it. I will describe the research more thoroughly below, but don't hesitate to contact me if you have any questions.

What's the purpose of the research?

At the division for physics education research at Uppsala University, we are among other things studying the pathways to and through university physics. This research is important for the quality and development of physics education both locally, nationally and internationally.

My PhD project, which is a collaboration between the division for Physics Education Research and the Centre for Gender Studies at Uppsala University, concerns ideas and expectations about what it means to be a physics student and how physics studies should be approached. Some earlier research has shown that issues of identity and social belonging are important for students' experiences and study progress, but little research has been made about these aspects in physics education. To widen the knowledge about these questions

my project aims at exploring the experience of studying physics with an identity perspective. In particular I want to study a period that is a vital stepping stone on students' paths to becoming physicists: the start of a Master's programme.

What does participation mean for you?

To participate in the interview study means that you are interviewed for around an hour. With your consent, the interview will be recorded, otherwise I will take notes.

The interview will be starting from an interview guide with different themes and questions, but it is important that your story plays the main role during the interview. You can always decide which questions you want to answer and which you don't want to answer and I will respect that.

Your participation is entirely voluntary. You can always, both before, during and after the interview choose to withdraw your consent to participate without specifying why.

That you choose to participate means that you accept that the material will be used for physics education research at Uppsala University. The material will be used to explore students' experiences of studying physics. You can at any time request to get a copy of all information concerning you or, before the results have been published, choose to withdraw your participation.

How is the research done and how will the material be treated?

The study will proceed both through participant observation of some classes and other activities and through interviews with some students on the programme about their experiences of beginning a master's programme.

After the interview, I will make a transcript of parts or all of the recorded interview, and this will be the text that I primarily use for analysing the interview. Together with notes from observations, this material will be analysed with the help of theories and concepts concerning education and gender, among other areas. The anonymised texts will be discussed with my closest research colleagues when preparing publications based on the interpretations of the material.

It is important that you understand how your integrity and your personal information will be protected throughout the whole research process. Personal information means data like your name, workplace, address or phone number or other information which can connect you to the study. This kind of information won't be present in transcripts I make of the interview. You will be given a false name, a pseudonym, and if there's a risk that you might be identified

via some specific episode described in the material it won't be spelled out in detail in any publication.

According to Swedish law, authorities like Universities are required to archive research material. The material from this study will be archived in a secure way on encrypted or locked up media, and no unauthorised person will have access to the material.

The results will be published in academic journals and in a dissertation. The study will also be discussed at scientific conferences before and after publication. All personal information will be anonymised in publications and discussions at seminars and conferences. When the publications are finished I will send you a copy.

Contact

Feel free to contact anyone of us if you have any questions.

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Signature

I consent to my participation in the study and the way my personal information will be treated:

Signature	Printed name	Place and date

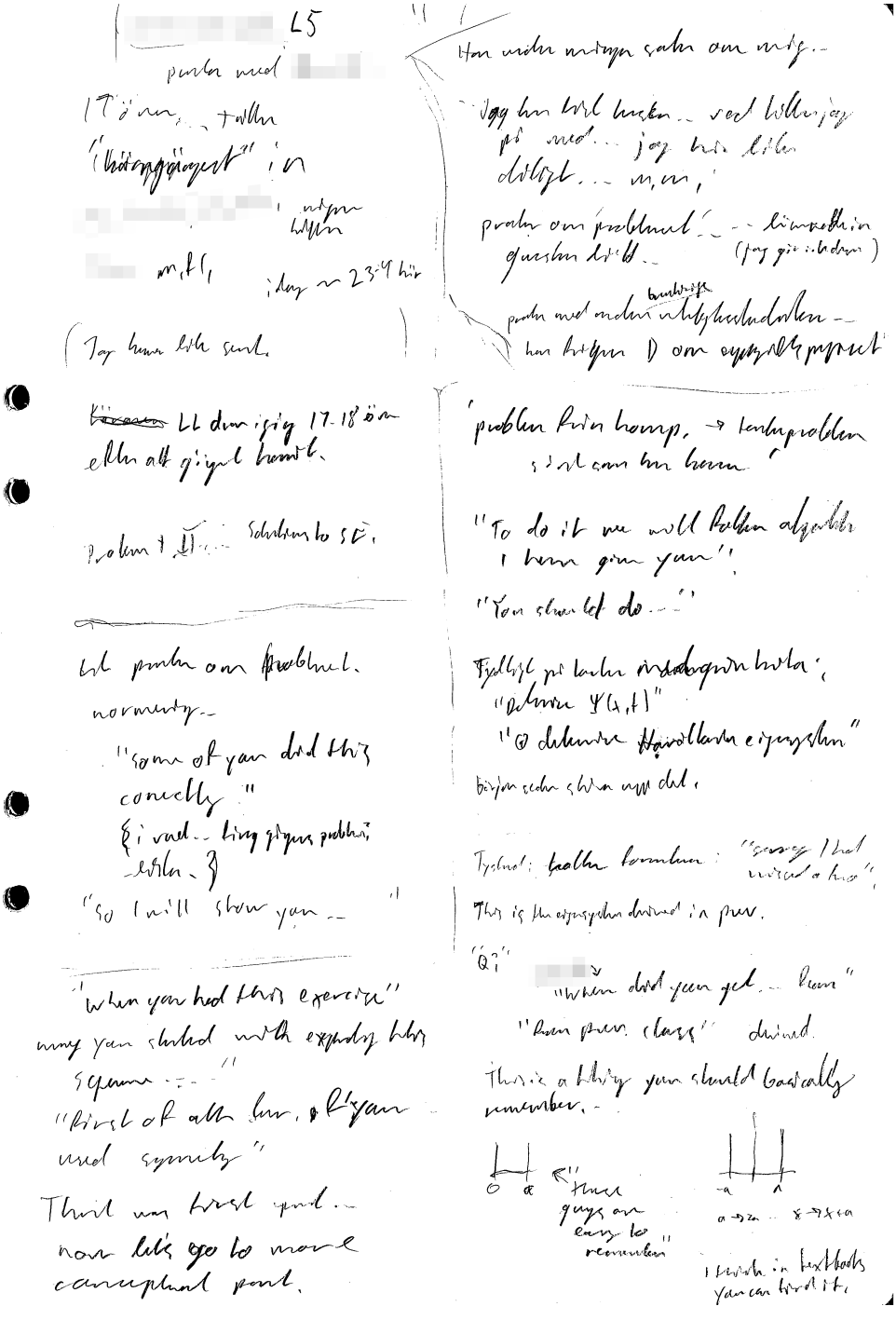
Appendix B.
Interview guide for Papers IV and V

This is the interview guide used for interviews with master's students. The interview was semi-structured and thematic, i.e. the interviewees' narrative was foregrounded. Hence all questions listed here were not asked but rather represent tools that I *could* use to take the conversation forward. Some questions are displayed in italics and represent topics that I did not want to miss raising.

- Introduction
  - Who am I and why do I make these kinds of interviews? Physicist, gender studies, physics education research, usually learning of concepts. But I look more at social stuff, what does it mean to become a physicist? That's why I want your story about it. What does it mean for you? So these kinds of interviews, they are not me only asking specific questions that I expect you to answer, but really about your experiences and stories. Than I put all this together, compare different stories etc.
  - English
  - Recording? OK, for me, to avoid misinterpreting things etc. confidential
  - You can choose to not answer or quit whenever you want to.
  - Three themes
    - Background: why physics, what physics etc.
    - Experiences of coming here.
    - Experiences and ideas about "becoming a physicist", directions etc.
- Background
  - Where do you come from?
  - When and why did you decide to study physics?
  - What did people think about that? Parents and friends?
  - *Why did you come here?*
- How was it to come here?
  - What was your expectations?
  - What happened then...
  - In coming to the department?
  - Could you tell me a little bit about these first weeks/month? How have they been?

    - Have you been surprised by anything?
- What direction?
    - Were you into some specific kind of physics from the beginning?
    - Has that changed? Have you changed your views? Why?
- *How did you choose direction here?*
    - *How do you think people view your kind of physics?* Other kinds?
    - People in general? Students? Physicists?
- Classes?
    - What courses?
    - Do you go to them? What do you do there?
    - *Could you describe how it feels sitting at a lecture or lesson?*
        - Engaging, boring, funny, interesting?
    - What is the atmosphere, or mood, in the classroom generally like? *Does it vary?* Other experiences?
    - Is there some behaviour that is right or wrong in the classroom? Strange? What would you not do?
    - Do you ask or answer questions? To whom? Do other people do?
    - *Quantum physics? Expectations? Earlier?*
    - Do you feel that you fit in in the courses?
        - Matches your previous experiences?
- Groups
    - who do you hang out with? Study with? International, local?
    - On your direction?
    - How was it before?
- Physicist
    - Would you call yourself a physicist?
    - What do you expect people would think about if you said physicist? Does that match with you?
    - Do you think you will be a typical physicist? Is there such a thing? What would people in general think?
    - Are you a typical physics student? What would that be?
    - Good physics student? Would that be the same thing?
        - Who says?
- (OPT) Quantum phys. Expectations? First quantum course? Now?

Appendix C.
Example of data and analysis for Paper II



The jottings reproduced on the previous page represent a small part of the total of 127 pages of jotted notes taken during my observations of different classroom activities in the studied quantum physics courses. The notes reproduced here are from a typical problem solving session. After my attendance at this session, I compiled the notes into readable form and did an initial coding as part of the analysis. The compiled notes of this session along with the final coding of segments are reproduced below. This particular session was given in English and the notes have been translated from my mixed Swedish and English for the inclusion here.

> At 18 minutes past, the tutorial teacher starts. Today the topic is solutions to the Schrödinger equation. He talks about the problem of normalizing correctly and says: ”Some of you did this correctly, but not all, so I will show you”. He discusses the problem that was worked through in an earlier session. ”When you had this exercise, many of you started with expanding this square... First of all, few of you used symmetry”. Then he shows how the integral can be solved in a slightly smarter way.
>
> (**coded as:** recommendation to students; student positioning; calculating practice)

> ”That was the first part, now let’s go to the more conceptual part.”
>
> It’s time to solve the first problem in today’s list. The tutorial teacher says that all these problems from the problem booklet could be chosen for the exam. He also says that to solve this kind of problem, ”we will follow the algorithm I have given you”, and repeats the information about the three steps from last time.
>
> (**coded as:** what we are doing; what you should do; calculating practice)

> The tutorial teacher writes in clear print on the board what has to be done: ”Determine $\Psi(x,t)$” and ”1. determine Hamiltonian eigensystem”. Then he starts to write the eigensystem for the infinite square well and says: ”This is the eigensystem derived in previous class” and asks if anyone has any questions. Simon (pseudonym) asks: ”Where did you get all that from?” ”From previous class”, the teacher responds and adds: ”This is a thing you should basically remember”.
>
> (**coded as:** any questions; student question; what you should know; calculating practice)

The episode described here, with a teacher showing how to calculate things and students at times asking about it represents typical classroom interactions in the observations. The codes ”what we are doing”, ”what you should do”, and a few others indicate explicit indications of expected practices from teachers. In the analysis, these codes were used as a way of looking into the practices constructed through the discourse in courses, which was found to be a viable way of continuing the analysis after the initial exploration of the material by me and my co-authors. In working through the analysis, an intermediary step was re-sorting coded segments according to specific questions such as

”what practice is implied here?” This re-sorting was done by exporting[1] coded segments and visually linking and grouping them using the concept mapping software VUE[2]. This was done in several steps for related groups of codes. For the extracts coded with codes such as ”what you should do”, the result of this sorting is displayed in Figure C.1 and in more visible detail in Figure C.2.

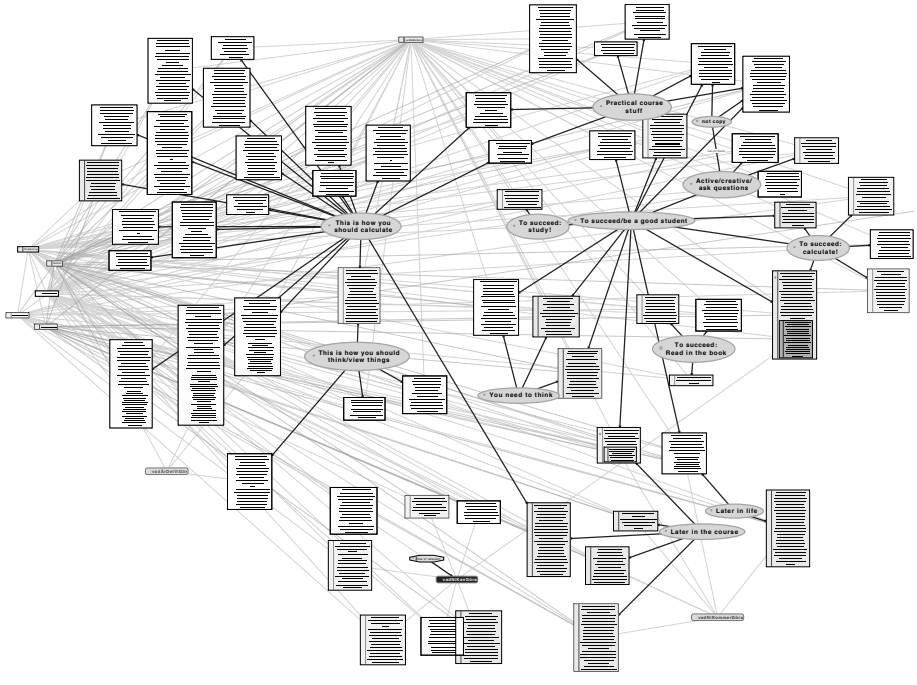


Figure C.1. Sorting of segments coded with ”what we are doing”, ”what you should do”, etc. in the analysis for Paper II.

This way of working through the material served as a guide for the qualitative interpretation and for getting a good overview of the material, but the sorting of codes in itself is not the complete analysis. For example, the work done in Figure C.1 indicated that the most common explicit messages about practices in the courses implied a calculating practice, like the extracts displayed above indicate. This taken together with the overall characterization of the observations pointed to the dominance of the calculating practice in the everyday discourse of the classes. There were however also examples of when other ways of practising quantum physics were conveyed in the classes. A longer example of this is reproduced below. Here, a more ”exploring” practice surfaces in the discussion about the implications of quantum measurement. However, in this case this is initiated by a few of the most engaged students,

[1]Tools for this are included in the orgqda package I developed for coding.
[2]Available from http://vue.tufts.edu/.

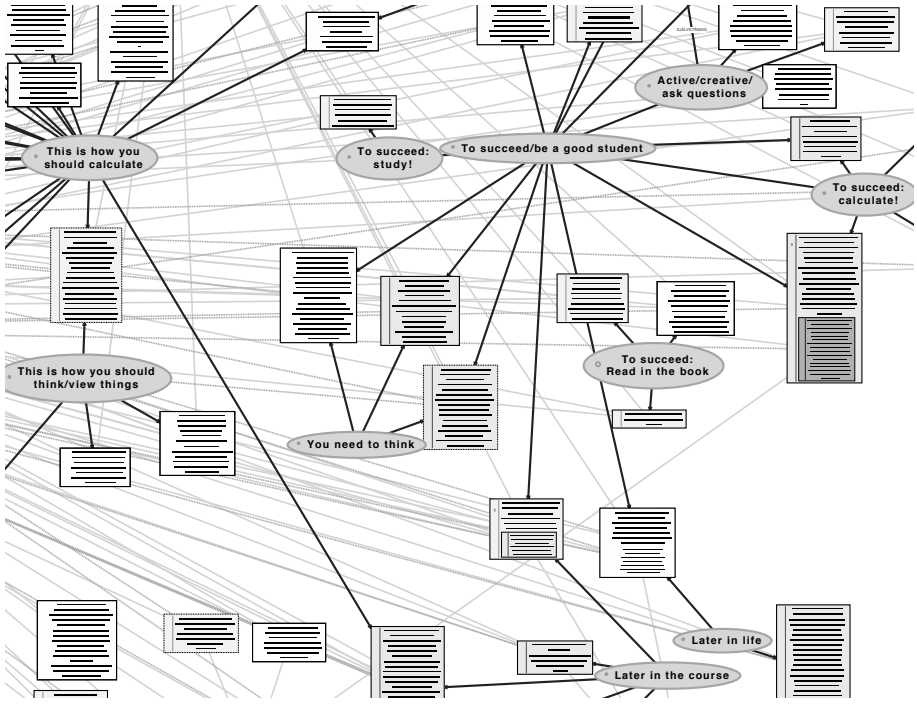


Figure C.2. Detail of Figure C.1.

and the lecturer does not dwell on the discussion but leaves it with saying it is all ”slightly abstract”.

it’s time for a break

Daniel, Karin och Niklas (pseudonyms) have apparently found something they found unclear in the first half of the lecture and go to the front of the classroom to ask the lecturer about it.

(**coded as:** student asks L)

After the break:

The lecturer starts by once again writing what was developed in the previous hour on the board. ”What we found at the end of the day was: $|\Psi, t\rangle = \cos\left(\frac{\epsilon t}{\hbar}\right)|+\rangle + i\sin\left(\frac{\epsilon t}{\hbar}\right)|-\rangle$.”

The lecturer says that during the break, several people have come forward and asked about measurement. The lecturer says and writes that when measuring ”you put your nose into the apparatus ... you change the state say at $t = T$ ... measure the state $|+\rangle$ and immediately after that the wave function has collapsed, $|\Psi, T\rangle = |+\rangle$.” The lecturer adds: ”You draw your apparatus back and let the system evolve, stick the apparatus back again and it has evolved. This is all slightly abstract”.

(**coded as:** abstract formal; philosophy of science; QMemblematic; exploring practice)

> The lecturer then starts showing a presentation on the projector. It's a description of "a particular system, if you are familiar with the Feynman lectures, this is how Feynman introduced quantum mechanics".
>
> (**coded as:** great physicists)

> The lecturer then shows how the ammonia molecule has two states, "up" and "down", with the help of some objects on the desk: the blackboard eraser, a box of chalks and a cup ("I'll borrow someone's cup for this", a few students laugh a little) are made to serve as hydrogen atoms and a handle to a pointer as a nitrogen atom. The lecturer shows with large motions how the nitrogen atom can be below or above the plane of the hydrogen atoms. "Below there", under the desk is impossible to show though.
>
> (**coded as:** joke; laughs; exploring practice)

Segments such as these which were initially coded with for example "philosophy of science" were sorted through similarly to the material described above. This yielded insights in the "other" practices to calculating that were conveyed in the classes.

Appendix D.
Example of data and analysis for Paper IV

The analysis for Paper IV proceeded first with a general coding process where different statements about quantum mechanics were categorized. An example of an extract that was given the code ”quantum mechanics as enticing” is reproduced below. It is from the interview with Bo, who describes his experiences of studying some quantum mechanics as a materials science student:

> **I:** but you said like quantum physics was when you realized physics was what you wanted to go into .. {**Bo**: mm yeah} when you took that quantum physics course .. why- why was that . why- what did quantum physics have compared to material
> **Bo**: mmm . mmm . ehh .. I'll see . . . do you know how the teacher teach materials course {**I**: ehh no} or . mmm . sometime they- for example when they talk about energy levels- or- energy levels {**I**: oh yeah} they just tell students ”there are some energy levels” {**I**: mhm} and students don't know how these levels- how these- why there are so many- why there are these levels they don't know why and the teacher won't go deep into these theories {**I**: yeah} and maybe the- the teachers just don't understand {**I**: yeah} so they can't teach and . but oh I- my . eh . quantum mechanics teacher in the bachelor {**I**: yeah} eh .. he is some amazing teacher . he told us many interesting little stories about quantum mechanics {**I**: yeah} and . and some relation between quantum mechanics to- to . classical? classical physics {**I**: yeah yeah} mmm .. they are inspiring I think {**I**: yeah} they makes- eh- a nice[?] teacher makes- makes students like me want to learn physics {**I**: yeah} but I can't remind some eh particular example he- he gave us . mmm . and also now let's see . . . and also it's the weakness of the students in eh material science {**I**: mhm} they don't want to know {**I**: yeah yeah} why is this . mm . maybe at first that they have- they want to go deep into the theory but then they find that there are too many things that they need to know {**I**: yeah} so they just give up and they only remem- eh remember some- some property {**I**: yeah} and the datas {**I**: yeah} and they when they- and they don't understand just the- they have resigned something . resigned {**I**: yeah yeah} that is their weakness and I saying[?] when they do some science research {**I**: yeah} it's weakness where you hinder- hinder the {**I**: yeah yeah} .. mmm .
> **I**: and you want to go deeper or to learn—
> **Bo**: —yeah I think a p- maybe I've- [interrupted by a machine]

This segment together with other statements from other interviews were read as indicating that quantum mechanics in particular could be a way of

building an interest in physics. Other themes that emerged in this initial analysis pointed to quantum physics being viewed as important, but sometimes difficult both mathematically and conceptually.

In the extract from Bo, we can also see a comparison with others. Bo wants to learn quantum physics deeply, in contrast to his perception of the motivations of other students on the materials science programme. This kind of comparison can also be seen in the following extract from the interview with Ivo. This extract was initially coded as ”practical approach to quantum mechanics” and was one key to the development of the theme of the ”accepting approach”:

> **I**: yeah . yeah . have you been I think I- like quantum physics is kind of a funny field because like th- people have lots of expectations also for the quantum physics course (laugh) {**Ivo**: ehm} have it been like that that your like bachelor level or
> **Ivo**: you mean physi- people that actually study it or you mean people outside of physics
> **I**: yeah . maybe both
> **Ivo**: yeah because I find it strange if . eh someone ask me so ”what do you do” and I say I do quantum physics specialisation {**I**: yeah} then they tell me ”ah quantum physics oh . yeah I wish I could understand it” . and then usually I say ehm . so . ”I’m not sure I- I don’t think a lot of physicists would say that they understand (laugh) anything about it” {**I**: yeah} they know how to . I don’t know normalize a wavefunction or something like that {**I**: (laugh)} but (laugh) that’s about it . and so I guess maybe you- the- within people that do physics the expectations (laugh) may be much lower because {**I**: yeah} I think usually people from outside physics they expect ”oh you gonna understand everything if you do quantum physics” but . if you go there you learn . things about I don’t know angular momentum algebra or something and .. ehm {**I**: yeah} very abstract mathematical notation but then you still haven’t applied it to- to anything in the real world {**I**: no} so {**I**: no} it’s a- yeah- it’s a bit of a misconception of people that do not {**I**: yeah} do quantum mechanics maybe
> **I**: yeah but- but you and your like fellow students (laugh) you knew that you would get to know (laugh) if- be good at normalizing wavefunctions
> **Ivo**: yeah (laugh) I don’t know if they- if people have great ex- (he) I think most people maybe just see it as something you have to know {**I**: yeah} like in the sense of . it’s gonna be necessary at some point if you do- really want to do research {**I**: yeah} so I have to know how it works but I do not expect that professor to explain the world to me or {**I**: no} to- to gain like deep insight into anything it’s more like I’m expecting him to .. to teach me how to deal with the mathematical framework of quantum mechanics {**I**: yeah} and then I can still sort of apply it to something or not but yeah
> **I**: yeah .. yeah . not exp- not- you don’t expect the professor to tell you how to like (in silly tone) communicate with the universe (laugh) {**Ivo**: no (laugh)} or that kind of
> **Ivo**: (laugh) yeah no- I- I think he’s not gonna do that (laugh) actually I hope he’s not gonna do that because otherwise I don’t know . it’s gonna be strange

I: yeah . yeah I guess quantum physics has been like very much in this new age {**Ivo**: yeah} this kind of—
Ivo: yeah . that's right yeah they ha- people have this ehm yeah funny idea that … I don't know it- it can explain everything and eh I don't know … (laugh)
I: yeah I think dra- this kind of såhär- observer influencing the system whatever {**Ivo**: yeah} and drawing- drawing very strange conclusions from that or
Ivo: yeah it- it's things they heard maybe once and sss yeah
I: yeah that's weird .. so . but you yeah you know that you will get some new (laugh) mat- mathematical formalism {**Ivo**: (laugh)} that I can use . that's kind of quantum physics—
Ivo: yeah it's maybe . it's a bit more practical maybe {**I**: yeah} practical approach

Here Ivo positions people who expect "too much" of quantum mechanics as being outside physics, or as not really having figured out what physics is about. In comparing this account to the stories of some other interviewees, I could see a marked difference in the approaches to quantum mechanics. In re-reading and reevaluating the accounts of the students at this stage, the two different approaches detailed in the paper (accepting and withdrawing) could be discerned and described.

Appendix E.
Example of data and analysis for Paper V

This appendix gives a more detailed description of the material and analysis for Paper V by following the coding and development of one research theme. In the analysis, I was looking for master students' negotiations of positions of being or becoming a physicist. This analysis resulted in five related themes: a) some universities are seen as better than others; b) some physics specializations are seen as better than others; c) characteristics of a good physicist and physics student; d) the general public's view of physics, and e) the general public's view of physicists and physics students. These themes contain both coinciding and conflicting views and negotiations. In reporting the results in the paper, the first theme was excluded due to lack of space and to keep the story consistent.

The extracts reproduced here represent part of the development of the theme of identity negotiations in relation to physics specialization (b). We start by looking at an extract from an interview with Sara, which served as one of the motivations for looking deeper into comparisons of different fields of physics.

> [After having told the story of how she wanted to go into theoretical physics but switched subject after some bad experiences]
> **I**: yeah . ok . that's really- really- really interesting and also this kind of (laugh) diff- eh different kind of physics eh . I think this . yeah- I think a lot of people want to go into like theoretical physics and have this kind of I don't know (laugh)
> **Sara**: (laugh) yeah . yeah I think . I don't know . many people that I knew they were like "oh yeah, theoretical physics" .
> **I**: yeah . and do you know- do you know (laugh) anyone who has ended up in theoretical physics
> **Sara**: eh . yeah . but not like- eh most of them they just went for another stuff like applied things because {**I**: yeah} they also want to earn some mor- some money so (laugh) {**I**: (laugh)} they know that maybe in theoretical physics it's not that easy

(**coded as:** vs experimental *in category* theoretical; status *in category* theoretical; is difficult *in category* theoretical; making money)

Looking at this excerpt during the initial stages of analysis and reading it in relation to Sara's general storyline, my attention was directed towards the choice of physics specialization as an important topic in the material. One

of the choices students often need to make to some extent is between theoretical and experimental physics, and in this context Sara paints an opposition between these two. Such statements were captured with the code ”theoretical vs experimental” in the first round of coding. In subsequent revisions of the coding this was included under ”theoretical”, which was used as a category for capturing multiple codes about statements regarding theoretical physics in particular

Another example of an extract that was given the same code of ”theoretical vs experimental” comes from the interview with Alex:

> **Alex**: I jumped to the solid state physics {**I**: mmm} and he recommended a professor for me and . and that’s how I started to know and eh learn stuff about solid state physics and now I would- since then I’m really fascinated about this . {**I**: mmm} and ehm . about the theory but mostly about the experiment {**I**: yeah} and eh . I did my bachelor thesis eh on superconductors in a lab {**I**: yeah} that meant that I constructed a superconducting material and performed the experiments on it so I think now that I look back at it I consider this my time at the- in the lab . the most important and fun part of my bachelor {**I**: yeah} so yeah .
>
> (**coded as:** vs experimental *in category* theoretical; tinkering)

In reading Alex’s story, I recognized a positioning as a ”tinkering physicist” (see Danielsson, 2009), and when taking this position, Alex sets himself apart as someone who is meant to be in a physics lab, more interested in experiments than theory (although he does not paint a very strong opposition between doing theory or experiments).

Jan also discussed similar topics, although he positions himself differently (he ”never liked to touch things in laboratories”):

> **I**: (laugh) yeah yeah yeah .. you said also the difference between theoretical and applied physicists what do you think that is .. even though they have this common . getting a solution
> **Jan**: mmm [5 s.] I mean that- that’s a problem because in the last century . eh physics- physicists was eh- .. the same thing {**I**: mmm} I mean there was no difference between . and physics as a science was born in that way . {**I**: yeah} everybody was doing an empirical work and they discover something they develop a law or they . no {**I**: yeah} now it’s- I think it’s different I think that we have to manage with a lot of data information eh . new theories . . . so . . . I don’t know I .. I never liked to- to touch things in laboratories like {**I**: yeah} ”what I’m do in I don’t like that” and to do [undecipherable word] to collect data {**I**: yeah} to .. I don’t like that but . I have friends that like it {**I**: yeah} so I think that . . . I mean what we share is the concept but for example they need just the concept and . . . to look at it through the experiment {**I**: yeah} .. you know . they don’t need a whole development of theory {**I**: yeah}
>
> (**coded as:** vs experimental *in category* theoretical)

In the continued analysis, I used other codes to point to other aspects of this theme of comparisons between theoretical and experimental physics. A case in point is the meta-code ”theoreticians”, which collects segments where theoretical physicists or students of theoretical physics are mentioned and described in some way. In general, when analysing the material, I used the collected codes for wider overviews answering analytical sub questions such as: How are different fields of physics conceived of? Where do students place themselves? Are there oppositions? Are there incongruities in the accounts? Very important in this process was to work both across and within the interviews, so that each interviewee's account was read through for the general consistencies (or inconsistencies) in their discursive positionings of themselves, others and physics.

This is an interpretative process. The need for anchoring interpretations in a complete picture of the interviewees' stories can be illustrated with the following extract, which connects the theme of comparisons between physics subjects to physics student identifications. In this extensive discussion, prompted by a question about the ”typical physicist” (see interview guide in Appendix B), Sara describes the collaborative environment at her previous bachelor's programme, and in particular how some students, perhaps following the stereotype of the lone genius, did not want to collaborate. Remembering earlier discussions about Sara's negative experiences and what is considered smart, I asked whether these students were aiming for theoretical physics. Sara confirmed this idea and also described how one of her fellow students was ”corrupted” by being brought into the ”smart team”.

> **Sara**: yeah the same- the same stuff and that- yeah I think in the that whe- there we learned that we have to have each other to {**I**: mmm} try to finish everything and we had a lot of things to do so we had to split tasks and then sometimes someone did something and then explained it to everyone and yeah in the end you have to share and you have to .. to know how to ask help because if you aren't just very proud or I don't know and ”ahh I won't ask anyone” and then you will just drown in the- all the things that you have to learn and understand and do
>
> **I**: yeah {**Sara**: yeah} yeah so like the pride of these (laugh) proud people kind of
>
> **Sara**: yeah the- did went down . yeah at first we hated them because they were just like so smart but also so . I don't know . bad[?] people we didn't like them because they were always like ”oh yeah I understand everything” but then we were just all the same and in the end we could work in the same table and they were maybe not asking us but they were there and {**I**: oh yeah} and just like collaborating with everyone
>
> **I**: yeah .. that's a really yeah interesting kind of development (laugh) {**Sara**: (laugh) yeah} yeah because I guess there are always these kind of different types of people or different ways of studying physics and {**Sara**: yeah} people try to yeah . . .
>
> **Sara**: yeah but I mean there were always someone that stayed out always but ..

{**I**: yeah} I don't know most of them . . .
I: did that correspond to like people w- w- w- did all those people want to go into like theoretical physics or something like that or was it ..
Sara: the people that got like out or eh–
I: yeah or the people who thought they should do everything on their own or
Sara: mmm .. yeah .. I think that (laugh) actually the people that were like more into theoretical physics were more like .. they didn't like a lot to share with us {**I**: (laugh) yeah} but yeah I think . but there were just a few of them {**I**: yeah} maybe like two or three and we were like .. already into that so . yeah {**I**: yeah yeah} but . yeah those two or three were from theoretical physics {**I**: (giggle)} yeah (laugh)
I: yeah I don't know if it's (laugh) if it's a pattern but I guess it's {**Sara**: yeah [??]} kind of
Sara: I don't know and . I- I also for example one these guys that were always- was always like a part of us he's now like ehm his professor or his I don't know how to call it like the guy that direct his bachelor thesis he's the same professor that told me you- you are not smart enough to go to {**I**: yeah yeah} and now . he was like- this guy the guy that was studying with me is- was very a good person I think but then when he started to- . to be his- with this other guy it- now he's awful he thinks that he knows everything {**I**: (giggle)} and yeah .. he's like becoming one of those guys that just know that- think they know everything and feel so good about that {**I**: yeah} yeah

(**coded as:** boring *in category* theoreticians; elitist *in category* theoreticians; disidentification)

In this extract, we can also note the gendered aspects of Sara's story, where she, as an aspiring female physics student was reprimanded by a male professor, who later took another (male) student under his wings and "corrupted" him.

Taking Sara's story as a whole, she often described theoretical physics endeavours as fun and fascinating, but at the same time, from her experience, the people aiming to do theoretical physics as elitist or uncooperative. In my reading, this represents a negotiation of status around imaginary physicist positions, which can be recognized also in comparisons and positionings done by other interviewees. Looking at these stories together, I could see a general picture where many interviewees hint at different perceptions of fields of physics, but the ones who negotiate their position strongly are those from less highly regarded fields. In this way, the theme of negotiations in relation to physics specialization pointed to how some specializations could be seen as better than others. In the paper, I describe how some of these negotiations are done in relation to the general public's view of physics, physicists, and physics students, and how the stereotypes expressed in these discourses intersect with physics specializations. For example, how "nerdiness" may be seen as a general (and positive) characteristic of physicists but also a label that can be used to discredit those who may be given an unjustified status as smarter or better.

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