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Characterising the practice of physics as enacted in university student laboratories using 'Discourse models' as an analytical tool

Abstract

This paper explores how university physics students constitute the practice of physics as enacted in student laboratories. In the study thirteen students enrolled in an undergraduate degree programme in physics were interviewed about their experiences of laboratory work. Working from a conceptualisation of learning that draws on situated learning theory, the paper describes the analytical process leading to the construction of two 'Discourse models' of physics students as a way of capturing the students' descriptions of laboratory work. The empirical result is the characterisation of these two Discourse models; a 'practical physics students', someone focused on the execution of the experiment, and an 'analytical physics student', someone focused on the physics reasoning. The Discourse models are also discussed from a gender perspective.

Introduction

The student laboratory is a highly complex learning environment; in which university physics students are, among other things, expected to acquire understanding of theories and concepts, learn a scientific approach to enquiry and obtain an understanding of the scientific community (Séré, 2002). The key role of laboratory work in science education has prompted a substantial body of research, exploring, for example, students' conceptions of measurements (Buffler, Allie, Lubben, & Campbell, 2001; Kung, 2005), student epistemology (Havdala & Ashkenazi, 2007; Wickman, 2004), metacognition (Kung & Linder, 2007) and new approaches to teaching and the evaluation of these (Allie, et al., 2003; Karelina & Etkina, 2007). While previous research also has acknowledged the socio-cultural aspects of learning in the laboratory, framed in terms of coming 'to understand the nature of an expert scientific community' (Hofstein & Lunetta, 2003, p. 36) or as the ability to participate in a scientific discourse community (Rollnick, Allie, Buffler, Campbell, & Lubben, 2004), these aspects are surprisingly sparsely explored. In summary, research about learning in the physics student laboratory has largely focused on the effectiveness of laboratory teaching as measured against standards set by science educationalists (see, for example, the review by Hofstein & Lunetta, 2004).

This paper explores the physics student laboratory from a different perspective, that of the students, exploring how they understand the practice of the student laboratory. In doing so, I am interested in how university physics students in the context of laboratory work negotiate the norms of what it can mean to 'do physics'; how they are together constituting a localised physics student community – partly in response to the broader physicist community of practice. However, it is also important to recognize that the students themselves are producing and re-producing norms for being a physicist as they 'educate' one another in the appropriate ways of 'doing physics'. Sfard (1998) eloquently summarises this dual process of learning as participation and negotiation:

> …learning a subject is now conceived of as a process of becoming a member of a certain community. This entails, above all, the ability to communicate in the language of this community and act according to its particular norms. The norms themselves are to be negotiated in the process of consolidating the community.
>
> (Sfard, 1998, p.6)

From this perspective learning is not just an acquisition of memories, skills and routines; it is about forming an identity. By participating in the practice in a particular way we also contribute to making the practice what it is; thus, 'our experience and our membership inform each other, pull each other, transform each other' (Wenger 1998, p. 96). Drawing on the work by Wenger (1998) I would therefore like to argue that physics students doing laboratory work not are passively learning 'to understand the nature of an expert scientific community' or to participate in such a community, they are actively negotiating both the practice of the student laboratory and their own participation in this practice. The purpose of this paper is to characterise how university physics students constitute the practice of physics as enacted in student laboratories. In doing so the paper aims to make a contribution to our understanding of the socio-cultural aspects of learning in a student laboratory, and hopefully inspire physics educators to reflect both on their own and their students' practice in this setting. The paper also aims to make a methodological contribution to physics education research in that is explores the use of 'Discourse models' as a tool for characterising collective patterns within a practice, while simultaneously illuminating the tensions within this practice. The context of laboratory work is chosen both because of the centrality of this learning environment to physics education and because the complexity of this learning situation; while the laboratory teaching at the university in this study could be characterised as rather traditional it still presents greater opportunities for different ways of participation than many other learning contexts. All in all, it can be expected that the students in the context of laboratory work are able to construct a wide range of possible ways of being and becoming physics students. Next I describe the context in which the research took place and how the data for the study was collected, before moving on to a section presenting the theoretical framing, the analytical process, and the empirical results in an integrated fashion.

Research Context and Data Collection

The research took place at a well-established Swedish research university. The physics research prides itself with long-lasting traditions and has traditionally been primarily centred around experimental physics. The University's physics research is considered a high status activity, both within and outside the University. There are several undergraduate programmes that include physics. The students in this paper were all enrolled in a four year undergraduate physics degree programme. During the first year of study approximately one third of the students are women, and of the students who specialise in 'physics' (i.e. not meteorology or geophysics) in their third year approximately one quarter are women. Among the professors at the department less than ten percent are women. A year cohort of students specialising in physics consists of roughly ten to fifteen students. The attrition rate of the undergraduate physics degree programme is high; around fifty percent of the students drop out. The programme is study intense, with several hours of scheduled teaching each day. Outside the scheduled hours the students are expected to write laboratory reports, read the literature and work with problem-solving. The teaching of the undergraduate students is carried out in rather traditional forms: lectures in large lecture halls are combined with problem-solving sessions in smaller groups. Many of the physics courses also include a laboratory course consisting of approximately five laboratory exercises, which the students work on in pairs.

In contrast to lectures and problem-solving sessions the laboratory exercises are compulsory and last for about four hours each.

The research presented in this paper is part of a larger project that set out to explore university physics students' identity constitution. The empirical data used in this paper consist of semi-structured interviews with thirteen undergraduate physics students (six women and seven men), enrolled in an undergraduate degree programme. The interviewed students were in different stages of this programme, from the first to the fourth (final) year. I recruited the interviewees by visiting lectures and asking for volunteers. The selection of students was strategic: I wanted students from different years and ages, and was aiming for a relatively even distribution of men and women. The selection was not meant to be representative, but rather to reflect a diversity of students and possible identity constitutions. Each student was interviewed once and the interviews lasted between 25 and 70 minutes, guided by an interview protocol that was developed with a broad focus on issues regarding the students' experiences of doing laboratory work in physics. The themes brought up during the interview included, for example, what they saw as valuable skills to have and to develop for the student laboratory, what previous experiences they perceived as being useful, how they thought of themselves as laboratory students and what they considered the purpose of laboratory work. During the final stages of the interview issues of gender in physics education were explicitly brought up. All interviews included the same themes, but the order in which the themes were raised were adjusted to ensure a flow in the conversation. The interview protocol included examples of possible questions, but I also allowed for the interviewee to take the conversation in different directions, and, when needed, used follow-up questions for clarification and/or elaboration. The interview protocol in its whole can be found as an appendix in Danielsson (2009). The interview protocol was trialled with three students enrolled in an engineering education. At the start of all interviews I introduced myself as a PhD student in physics, explaining that I am doing physics education research, but consciously stressing my background in physics. By such an explicit positioning of myself as a physicist I constructed the interview situation itself as a physics community, as two physicists talking about the learning and doing of physics. Consequently, this allowed me to explore how the interviewees constitute their identities as physics students in relation to a physics community as opposed to in relation to, for example, the general public or an interviewer from a different discipline. The construction of the interview situation as a physics community thus contributed to a more nuanced exploration of how the students constitute their identities as physicists, and made their sharing of experiences related to the procedures and content of physics more meaningful. All the interviewees were native Swedish speakers, and consequently the interviews were conducted in Swedish. The interviews were audio-recorded and then transcribed verbatim, but with little additional detail: only longer pauses and obvious emotional expressions such as laughter have been marked. Interview excerpts used in this paper have been translated with the aim of capturing the meaning of the utterances rather than being literal translations. In the translations I have chosen to remove repetitions, stuttering and some colloquial speech, to enhance the readability. The analytical process is described in some detail in the next section, but essentially it consisted of repeated readings, of increasing theoretical depth, of the interview transcripts in which common themes were identified and refined in an iterative process.

Theoretical framing, analysis and results

In the following the analytical process (the development of the Discourse models) is presented integrated with the emerging results to clarify how the Discourse models were developed and refined. Further, I have chosen to spend a considerable amount of the paper on describing the analytical process because, even though the two Discourse models (summarised in the end of the section) is the main empirical result of the study, outlining how Discourse models may be applied as an analytical tool is also an important contribution. A detailed description of the analytical process is furthermore a way to ensure dependability and confirmability.

As described earlier, the empirical material on which this paper is based consists of transcripts of thirteen interviews with undergraduate physics students. In the first stage of the analysis I went through the interview transcripts repeatedly, looking for instances where the students described the work in the student laboratory. At this point my readings were guided by a conceptualisation of learning founded in situated learning theory (Lave & Wenger, 1991); thus, in broad terms, I focused on how the students negotiated their potential membership in the university-based physicist community of practice, rather than what skills and knowledge they had acquired in the student laboratory. In the students' talk about 'doing physics' I could identify numerous different descriptions of what they perceived to be suitable or not in the laboratory context. In some cases students expressed completely opposite views about some aspect of the work in the student laboratory, such as the value of reading instructions. For example, Lars clearly expressed that the instructions often were redundant and one should be able to figure out what to do without them, whereas David stressed the importance of reading instructions:

I: Why don't you do that [read the instructions first]?
Lars: No, I don't think it's necessary that you read 'put it there', that you can understand.
David: I think you benefit more from reading the instructions than just ignore them and try to figure out how the apparatus works right away.

I found these types of opposing views fascinating, in that they showed that the students were engaged in an ongoing interpretation of how to do laboratory work and at times made very different interpretations of this practice. In an early stage of the analysis I therefore went through the interview transcripts looking for such contradictory statements about working in the student laboratory. In doing so, what appeared to be two quite different approaches to laboratory work emerged, one focused on the tinkering with the experimental set-up and one focused on theory and analysis. A representative for the tinkering approach to laboratory work was, for example, found in Ann's description of her course-mate Mats:

Ann: Mats, he's an experimentalist! He's so much fun to do labwork with, because he really gets, he might not understand the theory at all and hasn't done anything and is tired and hasn't slept and he sure starts to tinker kind of! He's so very different, he really fits in a lab!

Several of the students expressing an interest in the more theoretical/analytical side of laboratory work also expressed how practical skills in physics were either unimportant or at least uninteresting for them personally. An example of this is David who simultaneously stressed the importance of theory and how he found the more practically oriented physics studies he encountered in secondary school uninteresting:

David: It [practical physics] surely fits some, but for me it rather counteracted the in terest sort of, I didn't find it fun to play with circuit cards and sit and tinker and so on, I, like, wanted to see the theory behind…

In many ways the two different approaches resembled Wajcman's (1991) two 'technological masculinities'. In her pioneering work on gender and technology, Wajcman argues that control of technology is at the core of hegemonic masculinity and she distinguishes between two different forms of technological masculinity: one based on physical strength and mechanical skills and one based on 'the professionalized, calculative rationality of the technical specialist' (p. 144). Furthermore, Wajcman argues that 'masculinity is expressed both in terms of physical strength and aggression and in terms of analytical power' (p. 145), making the masculine ideology of technology a very flexible one. Drawing on my own empirical data in conversation with the work by Wajcman I developed two tentative models of the students' descriptions of the physics student laboratory:

one model focused on the practical aspects of laboratory work and the other constructed largely in opposition to the first, where the students stressed how practical skills were either trivial or unimportant and instead they focused on the analytical aspects of doing laboratory work. However, a direct mapping of Wajcman's technological masculinities on to my material was now expected to be a fruitful way to proceed, after all her research concerned technology/engineering, whereas I was exploring a university physics education where many of the students are likely to become physics researchers. Further, while there clearly were similarities between the students descriptions of the practice of the physics student laboratory and Wajcman's technological masculinities there also seemed to be some major differences. For example, when the students talked about the importance of the analytical aspects of laboratory work, they also often mentioned other skills they saw as important, such as report writing and discussion. My analysis so far had been informed by a theoretical framework drawing on situated learning theory (Danielsson & Linder, 2009), but in order to progress with the analysis it became increasingly apparent that a more focused analytical tools was needed, and for this I turned to Gee's Discourse analysis (Gee, 2005). In refining the two different approaches further I applied Gee's notion of Discourse models, which gave me a structured way of analysing the interview transcripts for how the students conceptualised what it meant to them to be a physics student in the context of laboratory work. Thus, my analysis was henceforth focused on characterising physics student Discourse models. However, I should point out that Wajcman's characterisation of the technological masculinities continued to inspire my analysis and the development of the physics student Discourse models.

Gee (2005) explains that 'Discourse models are "theories" (storylines, images, explanatory frameworks) that people hold, often unconsciously, and use to make sense of the world and their experience in it' (Gee, 2005, p. 61). As such a Discourse model attempts to capture some main elements of what it can mean to be, for example, a physics student. In short, the physics student Discourse models I have constructed from the interviews with the physics students can be understood as stereotypical 'versions' of how to 'be' a physics student in the student laboratory, simplifying the complex practice of laboratory physics by focusing on some central aspects. As with any other kind of 'theories' Discourse models are simplifications of reality that 'attempt to capture some main elements and background subtleties' (Gee, 2005, p. 61). Thus, the Discourse models can help us to understand a complex reality by focusing on some central things and leaving out the details. Applying the analytical tool of Discourse models in my data analysis also facilitated a move away from a focus on the individual students, and their preferred ways of doing laboratory work, to identifying collective patterns. We learn the Discourse models from our experiences, but as our experiences are shaped and normed by the social and cultural groups we belong to (Gee, 2005), it is likely that Discourse models will to some extent be shared among the members of a community of practice. I would therefore argue that Discourse models can be understood as constituting a part of the shared practice of a community.

In essence, a Discourse model is a simplification of reality, embedding assumption both about what is 'normal' (for example, in terms of attitudes or ways of acting) and about what is viewed as inappropriate or atypical (Gee, 2005). Reading the interview transcripts from the perspective of identifying possible physics student Discourse models therefore focused my analytical gaze more specifically onto what the students talked about as appropriate, typical and/or normal for a physics student. Examples of what students see as in/appropriate in the context of laboratory work have been discussed above (reading of instructions; the tinkerer Mats as someone 'really fitting' in a laboratory). The students were often quite outspoken about what they saw as inappropriate behaviour in the laboratory; whereas what they saw as typical or normal was often more implicit. However, David, in the excerpt below, makes it highly explicit that, in his understanding, it is not only appropriate for a physics student to focus on the analytical aspects of laboratory work, it is what is 'typical', common and expected:

I: So what's interesting for you is the analysing, not the doing as such?
David: No, not the doing, it's the analysing that I find interesting and that I think… somehow I've got the impression that it's like that for a lot of people at our education since that's what the focus is on and that you know when you apply, that the focus is on the scientist who does a lot of analysis. Sure, you can end up in a lab, but still it's somehow the analysing that the focus is on, it's not the doing, it's the analysis.

Furthermore, in refining the tentative models into Discourse models I not only focused on what the students described as appropriate, typical and normal, I also looked for what was described as inappropriate or atypical. In identifying such dichotomies, the most central one remained the split between practical and analytical and I chose to label the Discourse models the 'practical physics student Discourse model' and the 'analytical physics student Discourse model'. Other commonly occurring dichotomies included reading/not reading instructions, an intuitive/structured approach to the laboratory work and finding the equipment interesting for its own sake/viewing it as a means to an end, but not interesting in itself. I also identified other characteristics and activities that very commonly associated with the core aspects of 'handling of equipment' and 'physics reasoning', for example, when talking about the importance of analytical skills students often also mentioned discussions, report writing and mathematical skills.

In the next two sections I present the final versions of the physics student Discourse models, illustrated with excerpts from the interviews. In the development of the Discourse models the main focus was on my empirical data, but needless to say they are also inspired by previous research, mainly concerning engineering/technology (Faulkner, 2000, 2007; Mellström, 1999, 2002; Wajcman, 1991), but also Hasse's (2002) anthropological study of Danish undergraduate physics students.

'The Practical Physics Student'

The Discourse model of the practical physicist represents one 'set of norms' related to the practice of the student laboratory. In this stereotypical portrayal of the physics student the handling of the equipment is seen as the core of the laboratory practice. The equipment is found as being interesting for its own sake, and practical skills in terms of equipment handling are highly valued. As mentioned earlier, this Discourse model resembles one of Wajcman's (1991) technological masculinities and can also be said to be related to the technician engineer described by Faulkner (2005, 2007). Within this Discourse model, reading instruction is seen as unnecessary and it is seen as inappropriate to spend too much time on analysis, rather than moving on with the execution of the experiment.

Thus, the Discourse model of the practical physics student is primarily centred around the handling of the laboratory equipment, the execution of the actual experiment. Paul, for example, talks about the experimental set-up:

I: But in the student laboratory, what do you view yourself as good at there?
Paul: Connecting stuff! … I'm fairly good at connecting, connecting things together, setting things up, get the stuff working, start the measurements and stuff like that.

Kalle, just like Paul, takes pride in his practical skills and uses the metaphor of working in a workshop to explain what is so appealing to him about working in a physics laboratory:

I: But why did you choose to study physics then?
Kalle: Always thought that physics is fun. But for me it has always been the experimental part, it's never been to become a theoretician or something like that…

I: What do you see as so appealing with the experimental then?
Kalle: Erm… It's this that… you can come up with solutions yourself then, and then you get…to manufacture these ideas then, even though it's not me who gets to do it, but it's the people in the workshop… But it is precisely that that's so appealing, that it's so close to working in a workshop really…
I: But you're not interested in doing the practical work yourself? You want to come up with the solutions and then give it away to someone else?
Kalle: Well, I'd like to do it all myself, but I'm not allowed to so to speak. It's the workshop that does the manufacturing, then, and that's a pity. Because I can do it just as well as they can.

While it is of course not appropriate or even possible or interesting to make any generalisations from a small scale qualitative study such like this it can still be noticed that the students who describe themselves as possessing practical skills are predominantly the men. The men's valuing of practical skills is well in line with Mellström's (1995) findings from an ethnographic study of two different engineering workplaces, a design and development division at a large car corporation and a small, high-tech enterprise. He found that the male engineers at both companies viewed technical skills, the ability to take care of a wide range of practical problems, as an important part of what it meant to be a competent man. This ideal, according to Mellström, is found in a variety of social contexts, but perhaps primarily in rural areas and smaller towns, and among the 'working class'. In summary, Mellström argues that, in Sweden, being practical has traditionally been valued highly and is also tightly interconnected with 'being a man' (Mellström, 1995). The male engineers in the study by Robinson and McIlwee (1991) also often celebrated the hands-on technical competence and were keen to demonstrate that they had this competence, even when their jobs did not require it.

Paul and Kalle, thus, both describe themselves as skilled in the practical aspects of laboratory work, but as seen in the excerpt earlier from the interview with Ann, where she described the tinkering Mats, practical skills are sometimes also valued by students who do not see themselves as possessing such. The same goes for Mia, who does recognise the value of practical skills, but does not regard herself as possessing such skills:

I: Is there a difference between what's important to be skilled at in the lab compared to other elements in the physics education?
Mia: Yes, well, it's more the practical in the lab. That you don't have, those elements you don't have otherwise, it's that you have to be able to convert the theoretical into practice and tinker together all the stuff and see that it works.
I: Is that something you like? That you feel comfortable doing?
Mia: No!
I: Why not?
Mia: I'm generally bad at tinkering…

Furthermore, the handling of equipment is to be done intuitively, rather than with the use of instructions, signaling a natural flair for experimental work. Thus, 'having a feeling' for the work, being intuitive, is highly valued. Consequently it is not seen as always necessary to read instructions, one should be able to just figure out or 'tell' what one is supposed to do, as pointed out by Lars in an earlier interview excerpt.

I would argue that such a dismissal of instructions can be understood in part as a way to claim a 'natural' ability to physics, in part as a way to show a more 'creative' approach to the laboratory exercise than the one prescribed in the instructions. That a non-rule following approach to laboratory work is sometimes regarded as desirable in the university physics context is shown in Hasse's (2002) anthropological study of a Danish undergraduate physics education. Hasse found that many of the university physics teachers regarded the students who did not follow the instructions to be more interesting and creative than the ones who did. This was, however, never made explicit to the students, and when asked directly, the teachers claimed that students of course ought to follow the instructions.

The focus on the handling of the equipment, rather than the analysis, also implies that there is a distinction between the skills needed in the student laboratory and skills needed in other physics learning situations. For example, Lars points out how you have to be more 'hands-on' in the student laboratory and have to get things going:

I:	What is important to be skilled at in the lab? Is it different things than in the lecture hall?
Lars:	Yes, it is, a lot of things that you should… You have to be very hands-on, things need to happen, it can't take too long to put the stuff together.

As discussed earlier, a Discourse model is also characterised by what is seen as not belonging, for example, in terms of what is seen as inappropriate behaviour. In the Discourse model of the practical physics student such inappropriate behaviour is captured as 'looking for too much understanding'; being too 'analytical'. This is captured in Kalle's retelling of how he found working together with a particular student in the laboratory quite annoying. Since Kalle had just previously told me about how important it is to be prepared before you come to a laboratory session, I drew the conclusion that what annoyed him about his fellow student was that this person was unprepared:

I:	Aha, someone who was unprepared?
Kalle:	No, but was looking for too much understanding all the time.
I:	OK.
Kalle:	Then it just gets frustrating in the end.

As Kalle's answer shows, my initial conclusion was incorrect. What annoyed Kalle was that the student he was working with was looking for too much understanding; was focusing too much on the analytical aspects of the laboratory exercise and, thus lowering the pace in which they could proceed through the exercise.

In summary, the Discourse model of the practical physics student is characterised by a focus on the practical aspect of doing laboratory work; the handling of equipment and the execution of the actual experiment. Being handy is highly valued. This Discourse model is related to the utilitarian and technological purposes of tinkering described by Parsons (1995), that is, an interest in fixing devices because it is perceived as useful for everyday life and a fascination by the experimental devices in themselves.

'The Analytical Physics Student'

In the stereotypical description of the student acting in the physics laboratory, represented by the Discourse model of the analytical physics student, the primary focus is on the physics reasoning, as taking place both through application of theory, logic and mathematics, as well as more conceptual discussions. The analysis is found to be the most interesting part of the laboratory exercise, rather than the actual execution of the experiment. This focus on analytical skills is something the Discourse model has in common with the second technological masculinity described by Wajcman (1991); that of the 'technical specialist'. However, the analytical physics student is not just only concerned with analytical power, it also focuses on the social side of laboratory work, thereby illuminating the heterogeneity of scientific practice. Being skilled in equipment handling is seen as relatively unimportant; instead preparatory assignments, reading of instructions, and report writing are stressed.

In the Discourse model of the analytical physics student the focus is on the 'physics reasoning', the discussion and the understanding of theory, rather than the laboratory exercise as such:

Lisa: I think it's the most fun when we go through it, when we've done the lab and are to write the report and will figure out the theory part and draw conclusions from the results we've got, such things…

This is in agreement with what Parsons (1995) described as 'scientific tinkering'; to be more interested in understanding the theory behind the experiments than the actual execution of the experiment. The importance of the discussions is emphasised by Ann who often find the laboratory work to be very abstract. What is important for her is how she, through prolonged engagement with the material during the laboratory sessions, gains insight into the theory:

I: What do you see as the purpose of doing labwork?
Ann: That you should understand what you're doing in a larger context. …
I: What do you mean by 'understand what you're doing'?
Ann: How should I put it? The labwork as such sort of… But as an example, now that we were doing nuclear and particle physics, then you've been reading about different decays and beta-decay and everything, but then it becomes so clear that, yeah, annihilation that's them and from the positron you get that… so really I see the labs as a way to study, because you understand what you've earlier been struggling with, it falls into place.
I: Because you do it in yet another way?
Ann: No, maybe because you talk, you think so much about the same thing an entire day.
I: So it's not the labwork as such, it's more that you work in a group and discuss…
Ann: Yeah, more that. Not [the lab] as such, because it's often very abstract, you see some curve or some line or some spectrum, most of the time I think it's… all the going through, that it's like studying for an exam kind of, 'aha, that's how it was!', that I think is almost the most important thing with the labs, that you understand the theory.

The importance of the social aspects of laboratory work, of being able to work together is further emphasised by Lina, who describes the ideal laboratory student as follows:

Lina: The ideal student is prepared, knows what to do. Talks a lot too, yeah, if you work in pairs it is very important that you work together sort of, because, that you've seen in some groups, that someone knows what going on, and the other one doesn't really follow. So, that you sit down and discuss, talk through what you're going to do, take good notes, print all the documents, and preferably discuss the lab directly afterwards, or write the report so you don't…

It is noticeable, though, that when the students talk about 'softer' skills, such as discussion, collaboration or writing, it is never done in opposition to the 'technical' side of laboratory work (whether the technical side is interpreted as practical or analytical skills). This contrasts with Faulkner's (2007) analysis of engineering: the engineers she studied frequently foregrounded a technicist engineering identity, a 'nuts and bolts' kind of persona, despite the heterogeneity of their daily practice. Consequently, even though they recognised the importance of 'social' expertise in their engineering jobs, this was not considered a part of the 'real' engineering. While acknowledging the major differences between studying physics and working as an engineer, I still find the ease with which the interviewed students incorporated softer skills into their physics student identities interesting and noteworthy.

Further, by using the metaphor of studying for an exam (in sharp contrast to Kalle's metaphor of working in a workshop), Ann signifies how, in the Discourse model of the analytical physics student, no sharp distinction is made between the laboratory and other aspects of physics education. This is also brought to the fore by Susan, who also emphasizes the importance of logical thinking:

I: So what is important to be skilled at in order to be a good physicist?
Susan: It's to be able to see connections I think, to be able to think logically and see connections, to be able to connect different things.
I: Is there any difference between what is important to be good at in the laboratory compared to other stuff?
Susan: No I don't think so.

In the interview excerpts below, Dan's and Lisa's descriptions illustrate how the focus here is not on the execution of the actual experiment; but rather on the preparation beforehand, the writing of the report afterwards, and the associated discussions. In Dan's description it can also be noted how he downplays the importance of the execution of the actual experiment.

I: What do you try to learn when you step into the lab?
Dan: Well, first you have to try to figure out what you're doing, but… What you do first is to make a mathematical model, because that's what you're supposed to do and then the thing is to get all, on one hand to get all the formulas right, yeah, and then all definitions in order to derive an expression and then check so that the expression you've derived agrees with what you measure in reality. So I think that the biggest challenge is the mathematical preparation really, if it's not a very complicated lab, because I mean… Carrying out the lab, that's only mechanical stuff you're doing.

I: What do you think the purpose of labs is?
Lisa: I think it's the understanding, when you write the report you really have to go deep and read in the books, understand what they say.

In the Discourse model of the analytical physics student practical skills are consequently seen as uninteresting, as described by David earlier who claims that the hand-on approach to physics in secondary school counteracted his interest in the subject, or Dan, above, who views the execution of the experiment as relatively trivial. The view of the practical aspects of laboratory work as trivial is also made very explicit by David:

David: But the lab as such, the experimental doings that everyone can manage, that's no problem and is there something you can't manage, then the TA:s can always help you. So that's nothing that hinders you…

Not only are practical skills portrayed as uninteresting, unimportant or trivial, the tinkering approach to laboratory work present in the Discourse model of the practical physics student is here seen as unproductive and unsuitable for the student laboratory. David makes it clear that what he views an unstructured tinkering is an unfruitful approach in a laboratory, dismissing the idea of working from intuition:

David: No, it might exist, but it doesn't work here. I don't think so, because it's not those kind of machines we work with, then it more becomes that you turn some knobs on random and then you might not get the correct values at all, you might not get the correct measurements, you might not turn the correct knobs at all so to speak, it's very, it's… At least I don't think you can have a feeling for something before you've seen it.

In terms of the actual practical work in the laboratory it is important to read and follow instructions, as pointed out by David (earlier), to be careful, and in general to have a structured approach to the laboratory exercise, as emphasised by Dan:

> Dan: What I'm good at? Well, trying to think calmly and structured, not to stress, because if you just hasten past some part of the lab, then it's easy that you miss something…

Similarly most students in Hasse's (2002) study valued a structured approach to laboratory work, but she also found the small group of students who did not follow the instructions, but instead played around with the equipment, were quite disruptive (even though, as noted earlier, their unstructured/creative approach was appreciated by many teachers). It can also be worth noticing that being structured and well-prepared are qualities that are often attributed to female science students; previous research has described female students as, in the context of learning science, 'doing what they are told', whereas the male students have a more playful approach to science and technology (Hasse, 2002; Jones, et al., 2000). On a similar note it can be pointed out that while the practical physics student is an identity that seem most easily embraced by male students, and that also is associated with men by the female students, all the interviewed women (and several of the men) identify with and/or aspire to the analytical physics student – just like the majority of women in Faulker's (2007) study of engineers identified more readily with the science base of engineering than with hands-on engineering.

Conclusions and Discussion

In some sense what I have chosen to label Discourse models do, in important ways, parallel 'the shared repertoire' of the physicist community of practice (Wenger, 1998). However, starting from the construction of Discourse models rather than making claims about the shared repertoire for me had the advantage of allowing for contradictory interpretations of the practice of the student laboratory without defining whether all the aspects of the Discourse models are in fact part of the same community of practice. This is not to say that a shared repertoire cannot hold contradictory elements, but a Discourse model perspective makes no claim as to whether these contradictory elements are contained within the community of practice. Letting my analysis be guided by a Discourse model perspective also facilitated an identification of collective patterns within the students' descriptions of the laboratory practice, in contrast to a categorisation of individual students. Further, starting from Discourse models is also a way of bringing the tensions of the practice to the fore: by analysis of the interview transcripts from the perspective of constructing multiple, possibly contradictory, Discourse models I found it easier to identify tensions that may be contained within the community of practice, instead of interpreting these tensions as representing the distinctions between different communities of practice. The tensions between the two Discourse models, for example, how the Discourse model of the analytical physics student downplays the importance of practical skills, and how the Discourse model of the practical physics student values an intuitive rather than a structured approach, raises questions about a potential hierarchy between the Discourse models. Could one of them be seen as more highly valued within the university based physicist community? While it may be tempting to characterise the analytical physics student Discourse model as the one of higher status, considering how several of the students dismiss the practical sides of laboratory work as trivial or irrelevant and how it can be seen as related to working-class masculinities as described by Mellström (1999) and Wajcman (1991), I would argue that it would be too simplifying to assert a hierarchical relationship between the Discourse models. For example, as discussed earlier, the university physics teachers in Hasse's (2002) study often interpreted students who did not follow the rules (i.e. the laboratory instructions) as creative and independent; as the ones suitable for a career in physics. Further, several researchers have pointed to the celebration of practical skills within engineering, even in engineering jobs where such skills are not necessary (Faulkner, 2007; Robinson & Mcllwee, 1991). It may also be that the status of the respective Discourse models is dependent on who is participating in a particular practice. For example, women's rule-following has been interpreted as a way of compensating for lack of earlier scientific and technological experiences (Nair & Majetich, 1995). In the context of mathematics, Walkerdine (Walkerdine, 1989, 1990) has argued that girls' high performance is interpreted by teachers (and sometimes educational researchers) as a result of hard work and/or rule-following rather than 'rationality'. The hard work and/or the rule-following is thus understood as a way of compensating for their lack of an essential 'something'. To end on a slightly provocative note, this puts female physics students in a difficult position: the Discourse model of the practical physics student may be difficult to identify with for many women and, in particular, to be identified with by others considering its strong bonds to masculinity. The structured approach characterising the analytical physics student Discourse model may on the other hand be interpreted as a lack of practical skills and creativity. Finally, I would once more like to stress that the Discourse models are purely analytical constructs, stereotypes if you wish, and individual students are not expected to fit neatly into either of the 'moulds'. Still, the Discourse models can provide useful starting points for discussions about what we as physics education researchers and teachers view as 'appropriate, typical and normal' practices in the students laboratory, and can increase our knowledge about our students and their interpretations of the practice of the physics student laboratory.

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