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Research Article

How Physics Courses Can Make Highly Valued Strategies and Dispositions Visible to Physics Teacher Students

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ABSTRACT

Students who aim to become physics teachers for secondary education partake in physics courses together with other physics students. The aim of this study is to understand what is valued, taken for granted, and possibly reproduced in physics teaching given for future secondary school physics teachers. This study is based on observations in classrooms, in two courses conducted over a three-year period. Field notes are thematically analyzed and themes emerge about dispositions and strategies that are valued in the teaching context. The courses' teachers are engaged in pedagogical development and explicitly dissociate themselves from traditional physics teaching. They stress the value of student participation. Physics is described as a difficult, important, and beautiful science. To be passionate about physics is highly valued, as is a willingness to work hard and collaborate. The modern physics researcher is put forward as an ideal. Students are encouraged to plan for a future in physics research, while teaching and pre-university physics are never mentioned as career options. Course teachers distance themselves from traditional teaching methods but stick to traditional views of learning outcomes and the students' future careers. This study shows, for example, how new teaching methods do not necessarily lead to new values. This could be seen as an implication for further research.

Keywords: teaching culture, teacher education, physics education

INTRODUCTION

In Sweden, prospective teachers preparing for secondary education study, on the one hand physics, and on the other hand teaching and learning in physics. Throughout their educational process, they experience, and are educated in, the logic of physics teaching. Many physics teachers to-be study physics together with other students, such as prospective engineers or physicists. At some higher education institutions, student teachers first obtain a bachelor's degree in two subjects. This is then followed by a two-year master's level teaching education, which includes required courses in pedagogy, subject-based teaching and learning, school placement, and a master's thesis in educational science. Subject knowledge may at that point have been studied for three introductory years and significantly contributed to the prospective teacher's view of the subject. It is common that a physics teacher's practice is shaped by their own university education in physics and the culture that prevails there. Even after finishing physics education, the teachers retain their physicist identities and reverence for the science of physics; which is shown, e.g., in their willingness for professional development in "pure" physics, but less so in physics education (Engström, 2011; Engström & Carlhed, 2014).

The purpose of this case study is to interpret and understand the prevailing approach in physics teaching given to future secondary school physics teachers. We want to understand what is valued, taken for granted, and possibly reproduced in university-level physics teaching. Prospective physics teachers encounter and can be influenced by these values and practices; this may affect their views of and attitudes towards physics and physics education. Therefore, we want to understand what highly valued dispositions and strategies emerge in physics teaching given to teacher students. Throughout the study, we are inspired by Bourdieu's (1984, 1996) theories of educational sociology. We strive to find and describe that which "counts", that which is recognized and valued, in a social practice. Through assets in the form of social markers such as experiences, interests, and ways of thinking, speaking, and acting, an individual can show that they belong.

The Science of Physics

Individuals who work in and identify themselves with the scientific field of physics are associated with rational, objective, hard and tough personalities (Keller, 1992). University-level physics education is often perceived by students as difficult and abstract (Angell et al., 2004). Yet, it is also characterized as having a high status, both generally within universities and specifically within teaching education (Johansson, 2015, 2018). Lemke (1990) describes how the subject of physics gets its status and how the experience of the subject is highly dependent on how teachers and students speak of and describe it. Lemke (1990) also highlights that physics is often held to be reserved for a few elite students who have specific dispositions.

University physics influences physics teaching at all levels of the educational system with specific positions and highly valued strategies that determine how individuals maneuver. An example of a strategy is that becoming a physics researcher is often valued more highly than becoming a physics teacher (Johansson, 2018).

Physics Education

The culture of physics education has been explored for decades, for example by Aikenhead (1996, 2006), Harding (1991, 2006), Lemke (1990, 2001, 2011), Roth and Lee (2002), Tobin (2009), and Van Eijck (2013). These studies show how physics teaching emphasizes specific goals and purposes and how and why some students feel included, while others do not. Physics teaching is described as a link between the science of physics and society.

University teaching in physics tends to have a strong focus on the subject's concepts and calculations. Its historical development, philosophical foundation, relevant contexts, or processes in the classroom, have not been studied to the same extent (Duit, 2014), in spite of their importance especially for prospective teachers.

The traditional lecture form, with one-way communication from the teacher, tends to be the norm (Höttecke et al., 2012). Carlone (2004) studied physics classrooms where innovative thinking about pedagogy was highly valued and innovative methods were used with the intention of increasing student participation. Despite this, students and teachers presented physics as a difficult subject where innate talent is required to succeed. A good student was described as primarily a good listener, a recipient of knowledge, and one who has high memory capacity. Physics teachers are key players when developing physics education to become more inclusive and embrace critical thinking to a greater degree.

Hasse (2002), who has also studied physics classrooms, found that the underlying traditional values that characterize a good physics student were not always consistent. Students were encouraged to strictly follow given procedures at teaching sessions. When students deviated from these on their own initiative, their actions were nevertheless highly valued by the university teachers, who praised their creativity and encouraged them to become future physicists and researchers.

Physics Teaching as a Social Practice

Speaking with Bourdieu (1984), the education system is an example of a social system. Higher education in physics is one part of it, and teacher education is another. It maintains a symbolic order that conveys the image of what the world looks like, how to gain knowledge, and what things are interesting, fun, and important (Bourdieu & Passeron, 1979, 1990; Börjesson et al., 2016). The symbolic order classifies people. Power relations are made visible, and some actions are taken for granted, while others are misunderstood. The social system thereby elects the selected (Bourdieu, 1977).

Specific physics teaching at a university can be seen as a social practice within the larger social system of education. A social practice contributes to the reproduction of values and norms (Bourdieu, 1984). An individual tries to enter a social practice in which an arrangement takes place. Through social strategies and activities, they adapt to the practice. Language, topics of conversation, behavior, etc. make it possible or impossible for an individual to break in. For some, the practice may be perceived as closed, while others experience it as open and comfortable. Education in a certain field provides important training in its topics and the logic of its practitioners. Education may thus function as an entry ticket to a social practice and a tool for social reproduction (Bourdieu & Passeron, 2008). The concept of social reproduction and the arrangement in a culture are also described in more general studies of educational systems (e.g. Bourdieu & Passeron, 1979, 2008).

University teachers and students thus find themselves in the social practice of physics teaching having different positions in a context where a certain order prevails. Teachers and students possess various kinds of resources, such as experiences and intentions, which are recognized as valuable depending on which value system is produced and reproduced. Dominant values are reflected in the social practice, and are expressed in different ways (Bourdieu, 2004).

Furthermore, Bourdieu (2004) explains that a social practice is not only a result of individuals' actions. Instead, it is characterized by a complex interaction between, on the one hand, a social context and its dominant values, and on the other hand, individuals who act in that context with their respective dispositions and capital. The practice should therefore, according to Bourdieu (2004), be seen both as cultural (a way of life) and social (humanly constructed). The practice is not constructed in people's minds but in the interaction between individuals and institutions (Webb et al., 2017). Bourdieu and Passeron (1990) describe how individuals who possess capital that is valued can play the game and have the mastery required within an internship. They explain how the education system is a social system with a certain symbolic order that is linked to society's hierarchies of power. A way of being can be valued in school and at university, and high educational capital becomes capital that is recognized. Educational capital is, for example, how you as a student can behave in the classroom or have good study techniques and knowledge of what is expected. In this social context, you also can reach important social positions, for example as a researcher, professor, etc.

In the social practice of physics teaching, the dominant positions (professor, researcher, and teacher) influence strategies, dispositions, and their respective values: how to learn, what to talk about, and what to value in your studies. The students and teachers who use highly valued dispositions and strategies are seen, recognized, and thus socialize.

There may also be disputes in practice, called classification disputes (Bourdieu, 2000; Bourdieu et al., 1994), about what should occur according to the social order (Carlhed, 2011). We therefore also want to understand possible dominating relationships between different positions.

MATERIALS AND METHODS

To investigate and understand physics education for future physics teachers, seen as a social practice, we conducted a case study. It took place at a Swedish university where prospective secondary school physics teachers study alongside other physics students. We are interested in the physics education practice that emerges when teachers instruct, argue, and discuss with students, as well as when students discuss among themselves in the classroom and during breaks.

Setting

Two different physics courses were investigated: classical mechanics (for first year students) and quantum mechanics (for third year students). The study continued over three consecutive years. We observed the mechanics course during two terms (10 weeks per term), years 1 and 2, and the quantum mechanics course during three terms (10 weeks per term), years 1, 2, and 3.

The student group consisted of future physicists, astrophysicists, medical physicists, and meteorologists, as well as student teachers. There were approximately 35 students in the quantum mechanics course each term, about half men and half women. In the mechanics course, there were 15 students in each round, of which a clear majority are men.

The teachers are referred to as Alpha and Beta. They taught together in the three rounds of the quantum mechanics course, and Beta alone taught the mechanics course. Both Alpha and Beta are interested in pedagogical development and explicitly try to implement modern, scientifically proven teaching methods in the courses. Alpha is still an active researcher. Beta has left their research career behind and now works exclusively with teaching, pedagogical development, and related tasks.

In the quantum mechanics course, the sessions are long (often three hours) and consist of three major phases: clicker questions, lecture, and group work. At the start of the session, students answer multiple-choice questions about their reading assignments for that day using so-called clickers (a kind of remote control). Correct answers give bonus points on the final exam, and participation in the clicker question session is used to log students' attendance. The lecture part is mostly a traditional lecture, but students are encouraged to ask questions. Blackboards as well as PowerPoint presentations are used. In the group-work phase, students are divided into groups (chosen by the teachers) who in collaboration solve problems from special worksheets related to the lecture's content. Each group consists of approximately five students and has a small whiteboard. The students have assigned roles; apart from project manager and annotator, there is also a sceptic and an explainer. The roles rotate between group members between teaching sessions. The purpose of the roles is to encourage discussion, practice collaboration, and make everybody take part in a problem-solving task. To get the students' attention, the teachers honk a large bulb horn.

In the mechanics course, the teaching sessions lasted for two hours with a break in the middle. The students sat at regular desks, with no fixed seating arrangements. The sessions consisted of lectures and exemplary problem-solving calculations carried out on the blackboard. The students were encouraged to comment and ask questions, and many of them did so.

Data Collection Methods

Data is collected through classroom observations. The intention is to study and interpret what dispositions and action strategies are valued, and therefore what could affect future physics teachers' views of their subject culture, as well as how it could be talked about and taught.

Observation took place during a total of 25 sessions distributed over the five course rounds, with emphasis on the initial sessions each term. On each occasion, two researchers sat at the back of the classroom, one on each side of the room. During group work and during breaks, the researchers moved to be able to hear as much as possible of the conversations between students. The observations were documented using field notes. After each session, the researchers compared notes to sort out any questions and ambiguities.

Data collection was conducted in accordance with the ethical principles of Swedish Research Council (2017).

Data Analysis Methods

The field notes were created with a theoretically-driven thematic analysis. Braun and Clarke (2006) describe the method as "driven by the researcher's theoretical or analytical interest in the area, and [...] thus more explicitly analyst-driven" (p. 84). The theoretical starting point for the analysis is that teachers choose their approaches, attitudes, and teaching strategies, and that students choose their approaches and strategies in relation to specific values. These values reflect a rationale that is both cognitive and cultural. Teachers choose to talk, teach, and act in the classroom in the way they find legitimate in the social practice of physics teaching. Through the analysis, teaching strategies, statements, teacher—student and student—student discussions, as well as different approaches to physics teaching all emerged.

The grounds for legitimacy can be found on the one hand in the science of physics, and on the other hand in educational science: pedagogy and physics teaching and learning. The content is characterized by truth-seeking, explanations, calculations, and definitions of concepts. Strategies and statements that have emerged in physics teaching have therefore been analyzed and related to the fields of physics and pedagogy, respectively. Depending on what is highly valued in these fields, we can also find what constitutes highly valued strategies and dispositions in physics teaching as a social practice (cf. Bourdieu, 2000, 2005). Teaching and teachers' positions on content and methods as well as students' attitudes are thereby related to symbolic values (Bourdieu, 1984).

RESULTS: HIGHLY VALUED STRATEGIES AND DISPOSITIONS

Through analysis of the field notes, themes emerge that make valuable strategies and dispositions visible and show dominance in the social practice. We see how the teachers position themselves, and in different ways, relate to the subject's character, the teaching act, and the students.

Collectively, the themes presented below describe current physics teaching, understood through strategies and dispositions, dominant relationships, and a struggle.

A Successful Physicist is Disciplined and Hard-Working

In the social practice of physics teaching, an order is established where hard work is praised and encouraged. Students are organized into routines and control systems through prescribed procedures. Explicit references are made to scientific studies of teaching and learning that show how repetition and collaboration aid learning. Thereby, pedagogical research gets some of the shine of physics and a symbolic order is established, with scientifically founded learning high in the hierarchy.

Repeatedly, both Alpha and Beta emphasized the importance of hard work. Beta:

> "The quantum course does not consist of lectures, calculation exercises etc., but of lectures, *seminars*, and calculation exercises. [...] Only the strongest students are able to manage calculation exercises [...] To be able to answer the clicker questions, you need to prepare. Read the book and do the exercises."

Alpha continues:

> "Each teaching session is based on you being well prepared. We do not repeat content but assume that you have read. It's different in this course."

Beta begins their reviews during the quantum mechanics lesson by asking students about their preparations:

> "How has it been with the addition of momentum?"

Some students laugh. No one answers. Beta refers to the reading assignment. Alpha also wants to guide students towards increased understanding of the subject and encourages students to "think like physicists" without explaining what it means.

The enacted physics teaching includes both fixed routines and benevolent guidance. Beta says:

> "The course [...] has a special position because it is a qualifying course. Some previous courses are extra important, such as linear algebra and wave motion theory. If you have forgotten about base changes, vectors, and matrices, look in the supplementary material".

They try to guide the students towards good routines:

> "Do you see how easy it will be if you draw a good diagram?",

and continues:

> "Do not rush past the beginnings of the solutions. Think first, do not just use formulas. Go through the steps in turn: 1. summarize the information contained in the task, 2. analyze which laws are applicable, 3. algebra, and 4. check plausibility. The aim is for it to be as clear as possible for yourself or for those who are going to read your solutions. You should describe each step in detail, as if you are going to show them to someone else."

Alpha's and Beta's instructions for the clicker questions state the need for control. Alpha says:

> "We will go around and check. Set aside your books and notes on your own initiative every time in the future".

Beta continues:

> "No talking, no peeking. We are obliged to report all suspected cheating. Do not talk at all. No giggling. Do you agree with that?"

Both teachers strive to explain the benefits of scientifically-proven pedagogical methods to the students. Alpha shows a video of a boy who very quickly stacks mugs in certain patterns.

> "Champion cup stacker. Activity in the brain. [...] What is the message of the video? Anyone dare to answer?"

A student answers:

> "That we should study a lot."

Alpha laughs and continues:

> "Even if you have no talent, practice makes perfect. Practice, practice, practice, and get feedback. 10,000 hours to reach world class in anything! Talent is overrated! [...] This is a demanding course. But last year, 90 per cent had passed after two re-examinations."

Alpha refers to research:

> "It's about research-based teaching. A class of 250 students was split into two groups, with the same learning objectives, the same exam, the same time. One group has an experienced teacher, and the other has a post-doc applying proven methods for efficient learning. [...] This was such a great result that it ended up in [the journal] *Science*! Many students taught by the experienced teacher performed worse than chance. Traditional teaching can actually impair learning!"

Alpha and Beta stress that their teaching methods are not just a whim, but scientifically proven to be effective:

> "Everything we do is based on research. Various experiments have been done, and this approach seems to work well... This is not something we have made up."

A Successful Physicist Collaborates

Repeatedly, Alpha and Beta stress the need for collaboration. The idea of the lone genius is antiquated; a successful physicist of today is a team worker. They try to convince the students about this through the mandatory group-work sessions, and by constant reminders and verbal encouragement.

During a session on quantum mechanics, Beta and Alpha enthusiastically talk about a group task, where each student is assigned a role. Alpha:

> "Now we will work with the roles. We expect you to work. You get points for working, not for looking at your mobile phones. Do not look at your phone. If we notice that you do, you will not get any points."

Beta breaks in to lead the conversation towards the group's work:

> "Most people work, there are only a few who sit passively. Try to involve everyone. Why are we doing this? Why do we want you to sit and work in groups? Does anyone remember? We told you earlier at the first session."

One student replies,

> "To force people to explain."

Beta says defensively:

> "Not really 'force'. There is no intrinsic value in forcing you."

Another student says:

> "Learning to work in a group."

Beta nods and continues:

> "We had a meeting with alumni yesterday, and they said that they really need to be able to explain things to others. Many who work at [a named Swedish company] need to do so."

A third student emphasizes:

> "When you explain, you remember better."

Beta continues:

> "You understand better. You learn when you explain. Both [Alpha] and I would have been less successful as physicists if we had not worked in groups."

A student who has previously been silent asks:

> "How much did you work in groups during your education?"

Alpha breaks in and answers:

> "Not at all!"

Another student says emphatically:

> "No, we have noticed that within the university's physics department!"

Alpha uses both their own experiences and examples from other academic institutions. They refer repeatedly to the advantages of "thinking like a physicist", and continues:

> "In the United States, you sit a lot and work in groups. Nowadays it's not about IQ, but more about EQ [Alpha writes 'IQ' and 'EQ' in huge letters on the board]. Those who sat in groups when I was in the US were the best, they thought they were the best but you need to check things with other people."

A student raises his hand and says:

> "I just want to thank you for the opportunity."

Another student exemplifies with his own experiences:

> "I think it is good for me, with my poor study skills."

Beta confirms,

> "Research shows that it is good for everyone."

Beta also emphasizes how group work is commonly a cloud of concern:

> "We both have bad experiences from school, with people who do not take responsibility and so on. We need to manage it for it to work well."

Beta emphasizes how important it is to develop the ability to work in a group and connects it to the assigned roles:

> "Group work is training for future working life, where you won't be able to personally select colleagues. It is good training for handling such a situation."

When a female student asks if the same groups are to be used for the group work as during the calculation exercises, Alpha answers quickly:

> "Yes, research shows that this is good."

The group work enables certain individuals to develop valuable dispositions and strengthen their positions as "skilled" physics students. At the same time, the division of roles means that students are forced into special types of action, which not everyone is comfortable with.

Alpha and Beta take turns between the groups, guide them, and answer questions. Some groups write on their boards all the time while others use their notepads. Beta occasionally reminds students of the purpose of the course structure:

> "The purpose of the group work, I want to remind you, is to make you learn as much as possible. I want to point out that the group work is not graded and that it is not about getting through as much information as possible. Make sure that all group members are involved, the goal is for everyone to gain an understanding. Introduce yourself to each other if you do not know the others' names, I assume that you have done so. The goal is for you to help each other learn."

As the course draws to a close, Alpha reveals one hitherto hidden aspect of their pedagogical approach, namely that success is important:

> "Do not disappoint us [at the exam], we want to be right, so think it's good. You can participate in physics research, if anyone is interested, I will apply for research grants, not from the state, feel free to join if you want to do research."

A Successful Physicist Always Shows a Curious and Scientific Attitude

Throughout the conversations that take place, it becomes apparent that it is important to appear to be a committed, curious, well-read, questioning person with a strong interest in physics; this is more important than being able to answer correctly every time.

Most of the students stay in the lecture hall during the break, as do the teachers. There is an open environment, and the students seem comfortable when reaching out to the teachers asking questions. In this social practice, conversations become important. The teachers are available at all times. In conversations between students, it is clarified which issues and themes can be addressed and discussed. The conversations that are worthy of participation are singled out, and valuable dispositions and strategies thereby identified.

In both courses, Beta appears to be friendly, inviting, and knowledgeable. The mechanics course's content can easily be related to everyday situations. Before starting a lesson, Beta and the students talk about motorcycle driver's licenses and protective clothing for motorcycle riders. One student says:

> "You feel like a superhero … Why doesn't a bicycle fall?"

Beta answers:

> "Momentum. You will learn about that in the next mechanics course. If you only have gravity, it takes a while before it has an impact. The motorcycle has a low speed, so you turn the handlebars as usual. At a higher speed, press left if you turn left."

During the actual mechanics lecture, Beta allows students to interrupt if they stick to physics-related issues and topics. A student suddenly said:

> "There was a man who dropped two balls from the tower of Pisa. It can't be Newton, because he was not Italian."

Beta allows this rumination and asks:

> "Who can it be then?"

Another student answers:

> "Galileo, that sounds Italian."

Beta confirms:

> "Galileo was the first to do this experiment. [...] Now let's move on. It's about Newton's second law."

Beta values and encourages conversations about more easy-going physics topics. During the break, Beta participates in conversations about physics that are not directly related to the lesson's theme, and thereby contributes to the establishment of the social practice's valued conversation topics.

> "They have just announced the Nobel Prize. Topological quantum materials that arise in one and two dimensions. In two dimensions and one dimension arises… It is not exactly two-dimensional; electrons are trapped between two semiconductors so that the electrons can only move in two dimensions."

A student enters the conversation and gives feedback on the previous discussion about Galileo:

> "I have seen… Youtube with Galileo's experiments in a vacuum chamber. They used a feather and a bowling ball … If they have something like this [vacuum chamber], why have they not tested it before? That seems completely surprising."

During the students' group work in the quantum mechanics course, there are constant conversations about the assigned tasks. A student in one of the groups stands up and presents his hypothesis for the use of a formula while the others sit down and argue against it. Alpha passes by, takes a look at the calculation and asks with a humming voice:

> "Should there be a plus here as well?"

The student who stands up answers:

> "Yes … or no, it should be a minus. I probably do not know."

Alpha points out that whether it should be a plus or a minus is significant and ends the discussion with:

> "It would be a big mistake on the exam."

The group work gives the "talented" physics student a chance to show off; the person in question is well-read and can relate to the textbook's content during discussions. In another group, a student also stands up and presents his calculations on the group's whiteboard. Beta comes by and addresses the standing student, not the whole group. The "skilled" physics student—the student who can talk and discuss using textbooks and likes to stand up and show a physical advantage—is acknowledged over and over again by the teachers.

A student who has talked to Alpha throughout the break begins to question another student's contribution to the group's task. The designated student has found other calculations in the book and presents those. Alpha comes forward to the students, reads and tries to understand, then goes to Beta who consults another book. Alpha returns to the student group and says:

> "Excuse me, that is in fact correct."

The designated student seems to possess information that Alpha was unaware of, which leads to their apologizing.

Physics students who are knowledgeable and prone to discussion are valued. Alpha and Beta repeatedly state that they value questions and conversations even though they cannot always provide solid answers.

Some students frequently ask questions, seemingly not always to get valuable information, but to show and make sure that they follow. This approach seems to be valued by the teachers who smile, nod, and confirm in different ways. In general, students seem to pose content-related physics questions to Alpha, while Beta is asked about administrative issues and further physics studies. Mainly it is the female students that ask questions of the latter type.

Conversations about physics seem to be important. By participating, you are let in. This applies both during formal group work and in informal conversations during breaks. Students discuss mostly subject-related topics such as an exam in mathematics or a computer program that is messy and works poorly. The students also talk about everyday things and commonly comment upon these using scientific concepts and terms. A female student says that she needs a pain reliever and finds a pill in her bag:

> "What is the difference anyway? Is it paracetamol in everything else?"

Other students comment upon how hair helps to keep the head warm. A scientific approach is valued in this social practice.

In summary, the conversations in current physics teaching can be described on the basis of social markers that involve valuable resources. The conversations cover physics in different ways. To obtain a disposition that is recognized, one can question, explain and ask questions–be alert and interested. In their conversations, one should show interest in physics and physical phenomena and adopt an exploratory approach. This is done by asking exploratory questions, but also by emphasizing that you are well-read or have experiences that contribute to the conversation.

A Successful Physicist Finds Physics Fascinating and Intellectually Challenging

The notion that quantum mechanics is difficult is constantly present. At one point, Beta asks,

> "How many people find this counterintuitive and peculiar?"

Only one student raises a hand. Beta continues:

> "You who do not find it peculiar must think again."

In the beginning of the first lecture, a picture was shown to anticipate the students' worries and possible fears:

> "Quantum physics in a nutshell: This is crazy! It's crazy."

Beta describes how both mechanics and quantum mechanics are fun courses, but that they differ and are interesting in different ways.

> "Classical mechanics is intuitive and mundane. Quantum mechanics is the opposite."

Beta expresses a desire to confirm the students' possible concerns:

> "Nothing in the course should appear obvious or self-evident to you."

Alpha emphasizes:

> "Does it seem self-evident to anyone in this course?"

Nobody answers. Both Alpha and Beta are smiling. Beta asks students if they have any questions, but very rarely does anyone answer. Beta therefore poses a question to the group:

> "Should the expectation value be the same as the wave function?",

which makes Alpha burst out laughing. The students laugh too, and one of them says:

> "Weird!"

> "Good comment!",

Beta answers. The teachers maintain a light-hearted mood and allow the students to experience confusion. They do, however, emphasize the importance of understanding:

> "When you say that 'this is from the handbook of physics formulas'; it indicates that you do not know what is really happening."

The two teachers seem to want the students to confirm that the quantum mechanics course is difficult, and that confusion is *de rigueur*. Beta speaks kindly and seems to want to encourage the students and provide hope. A student asks:

> "Can you explain again?"

Beta:

> "Do not panic, it is not difficult. You will have to try it later."

Alpha also chooses to give vague responses,

> "It is possible, but it's not trivial."

Beta sometimes even avoids answering questions. The teachers do not seem to want to address things that may be perceived as too difficult or outside of the planned content.

Alpha and Beta want to try to get the students to think about physics in different ways than they previously did. They often try to enliven the mathematical formulas with jokes and highlight the aesthetics of the subject. Beta describes the Schrödinger equation and deems it humorously "maybe a little scary [laughter]". Words are also used in other ways:

> "Now let's start with the fantastic Clebsch—Gordan coefficients."

On another occasion, Beta describes the textbook as "the classic and fantastic Griffiths, *Quantum Mechanics*, blue edition [a well-known textbook in quantum mechanics, published in numerous editions since 1982]". Among other things, Alpha talks about Fourier's Trick:

> "What if y [psi] of x is not a 'nice sum'. Then you use Fourier's Trick… but the important thing is to be able to interpret this: Why should the equation be solved in an elegant way?"

The teachers also help to create a light-hearted atmosphere with physics-related anecdotes. Beta says:

> "You may know that Einstein was skeptical of quantum [mechanics]. He and Bohr discussed this in letters. Einstein would argue for an experimental setup where measurement would be possible, and Bohr would think about the problems with it."

Both Alpha and Beta laugh out loud and for a long time at that story. They try to show how physics is characterized by creativity and broad-mindedness, and on several occasions encourage students to "think outside the box".

In the social practice, physics is depicted as difficult, yet beautiful and elegant. The subject's difficulties and its unattainable element is respected and revered. The teachers talk about how there are still things that no one knows and that finding the missing pieces can lead to the highest honor in the field, a Nobel Prize. When a student expresses that,

> "You should know where the photon is when you know its trajectory and how it collides?"

Beta answers:

> "Develop your theory, write an article about it, and receive the Nobel Prize. The rest of us have lunch. [general laughter] Or do you [Alpha] have a quick answer?"

Alpha replies:

> "No, it will probably take 10 minutes."

The student who asked approaches Alpha by the blackboard and together with two other students get an explanation. The rest head off to lunch.

On multiple occasions, Beta expresses the high status of the Nobel Prize:

> "If you find an exception, show it to the Nobel Committee!"

and that

> "when you start studying quantum [mechanics], it is quite common to think that you have found a gap in the theory. If you do, it is surely a Nobel Prize"

and continues:

> "Quantum mechanics was established at the beginning of the 20th century. The measurement problem—what actually happens when the wave function collapses—is still an unsolved problem. Unfortunately, not many people research this today. Applied research is more common. There are not many people who work with basic questions about interpretation or what a measurement consists of. If you think it seems like fun, do a dissertation on it, but do not expect to crack it [...] Experience from the history of physics shows that the small subtle things that sit there gnawing at you are the ones that can change history."

Beta and Alpha present how unattainable physics can be, while trying to explain that it is possible to contribute to discoveries. Beta talks about measurements, probabilities, and how to interpret them. Alpha breaks in and emphasizes that an exact measurement is not possible, but that

> "you are welcome to ask [about it], the smartest people of the last century struggled with this."

Physics may seem unattainable, but it is partly achievable for those who are curious, creative, and patient; recognition in the field of physics requires "smart" people, willing to make a serious effort.

The Dominance Relationship Between the Physicist as a Teacher and the Physicist as a Researcher

In physics teaching, a dominance relationship can be discerned between Alpha, the teacher as a researcher and Beta, the teacher as a pedagogue. They have different strategies for student interaction. When the quantum mechanics course starts, Alpha introduces themselves to the students as a researcher and briefly describes their own research. They repeatedly refer to examples and anecdotes from their research career, which includes international postdoctoral work in a well-known research group. Beta introduces themselves to the students by name and then says that they recognize almost all students from a previous course.

Alpha can sometimes be perceived as a little uncomfortable in the teaching situation, expressing themselves briefly, often encouraging students to calculate and read on their own. Compared with Beta, Alpha points out more intensely that the quantum mechanics course is difficult and requires a lot of studying. Alpha takes a somewhat passive stance during the actual lectures and sometimes uses their mobile phone or computer during the lesson, which Beta never does. Sometimes Alpha corrects Beta during lectures. Their style seems relaxed and laid back, but they often ask quick questions and provide advice to students when they work in groups:

> "Study guides for each session can be found in the course description. Stay tuned! Calculate and read! Reading preparation, reading, recommended tasks, get in touch if anything is unclear!"

At other times, Alpha saunters slowly between desks and chairs, and sometimes appears restless. Alpha is often one of the first to leave the room when the session is over.

Beta asks students questions, provides feedback, and tries to make sure that everyone understands. They express care and interest, emphasize the fantastic and fun aspects of different formulas and of the subject itself. Beta provides the students with general advice and useful tips for current, previous, and future courses:

> "Let's think back to mechanics."

They walk around the classroom during group work, talk to all groups and actively look for the need of support. Beta discusses things with the students at length and often expresses that they should feel welcome and included:

> "Welcome to this calculation exercise… where I will take care of you."

After the session, Beta answers students' questions and is the last to leave the lecture hall.

Both Alpha and Beta are successful researchers and are perceived as highly skilled in the subject. Whenever given the opportunity, Alpha emphasizes their own special knowledge related to research—ongoing projects as well as finished ones and future applications for grants. Beta focuses more on giving students well-founded and comprehensible explanations. In physics teaching, the positioning of the teacher as a teacher on the one hand and as a researcher on the other is made visible. This is not in any obvious way linked to the level of physics knowledge, but to the level of patience and interest in students and their learning. Alpha often takes (or is given) the opportunity to end a discussion, to have the final word, whereby a connection to research is often made.

The Ambivalent Struggle Against So-Called Traditional Physics Education

Alpha and Beta argue for their teaching methods and describe them as different from "traditional teaching". They thereby make visible the ongoing struggle against "the other".

By emphasizing how group work benefits learning and that success demands struggle, the teachers present an image of the physicist as both social and hardworking. They try to reject the idea of the brilliant physicist as a lone genius or a person with special innate talents. Alpha's and Beta's physics lessons are said to be for anyone who is willing to make an effort. At the same time, they also mention physicists of yore with admiration and describe how the smartest can be awarded the Nobel Prize. In the teachers' actions, a reverence for talent and genius can be discerned. Methods that have the potential to help all students to succeed in the course are used, and the highly valued final goal is clear: to become a physics researcher and a future Nobel prize laureate.

DISCUSSION

This paper set out to investigate and understand which highly valued strategies and dispositions emerge in physics teaching, and then discuss how these may affect prospective physics teachers' views of and attitudes towards physics and physics education. We want to understand what is valued, taken for granted, and possibly reproduced in university-level physics teaching.

Through the teaching sessions in mechanics and quantum mechanics, a symbolic order becomes visible. The ideal physicist possesses certain traits, which are produced and reproduced in the teaching context. Most of those traits are traditional, while other are a product of the teachers' progressive pedagogical ideas and attempts to strengthen physics education by using modern, presumably scientifically proven, teaching methods.

Physics is described as a difficult subject (also found by Carlone, 2004). Especially the content of the quantum mechanics course is repeatedly described as counterintuitive and "weird". At the same time, the science of physics is praised for its beauty and sublimity. According to the teachers' messages, difficulties met when studying physics should be counteracted by hard work and collaboration. Physicists are not described as necessarily being exceptionally talented; through patience, commitment, and creativity it is possible for anyone to succeed. The ideal physicist is fascinated and awed by the science of physics and is willing to contribute to the field together with other physicists. The physicist also applies a scientific worldview to their everyday life (even when discussing seemingly mundane things, like haircuts), for practical reasons and for the joy of explaining and understanding. To let physics and physics-inspired reasoning permeate one's life and worldview is a highly valued attitude that is encouraged when teachers talk with the students and when students discuss among each other during breaks.

The two studied teachers, Alpha and Beta, have taken an explicit stance against traditional physics teaching and show an interest in pedagogy and novel teaching methods. This struggle is manifested in social practice, although slight discrepancies between what is said and what is enacted. Hard work and collaboration are valued, but a tendency to pay tribute to individual geniality shines through. This shows even in group exercises, which in many cases provide ample opportunities for individual students to show their brilliance. The formal or informal group leaders repeatedly seek respect and admiration from the teachers, sometimes on behalf of the group but more often on behalf of themselves. During group exercises, individuals' abilities to pose clever questions and partake in qualified discussions with the teachers were held in high regard. The teachers, in their dominant positions, encouraged and enjoyed this. Thereby their symbolic values were made apparent. A traditional view of the good student prevails (compare Carlone, 2004), even though classroom routines are different. To fit in, students have to live up to this; they have to possess a capital that matches the symbolic capital.

Many teachers, on university level as well as in secondary school, are influenced by their own physics education and reproduce values and attitudes in their own teaching. (Engström, 2011; Engström & Carlhed, 2014). By interpreting valuable dispositions and strategies, we can see what is reproduced in teachers' education and thus also most likely to influence the future physics teachers' own teaching of the subject. The current symbolic order guides the future secondary school physics teachers and will most likely affect their teaching strategies and actual behavior. In this light, it could be valuable and inspiring for prospective teachers to see these examples of alternative pedagogical methods not just in practice, but also have the opportunity to discuss their influence on learning and the classroom environment. This is, however, not actively encouraged. Instead, they highlight how their teaching methods will increase the chances of passing the exam and thereby get one step closer to a career in research. The choice of teaching methods is not justified through teachers' professional experience, but by the methods' being described in articles in highly ranked scientific journals. The virtues of the researcher are obviously valued higher than those of the teacher. Physics teachers or pre-university physics teaching are never mentioned, and teaching is not among the careers discussed. Instead, the researcher is repeatedly put forward as the ideal, even in this progressive learning environment. This dominance relationship between the teacher as a physicist and the teacher as an educator, where the researcher gets the final word, emphasizes the superiority of research. Even in the non-traditional physics classroom, students are fed with and/or tempted by the attraction of Nobel prizes, research at prestigious universities, and the inherent beauty of science (especially physics).

Students and teachers accept scientific knowledge, scientific literacy, and scientific curiosity as symbolic capital. Alpha and Beta praise new, science-based teaching methods, but without praising their potential future users or their profession. The idea of the lone genius is dismissed, but also idealized, even for the prospective teachers. The science of physics in and of itself is important, the ability to teach physics less so.

The prospective physics teachers could benefit from a greater awareness of the dominant relationships of the physics field. The teaching and learning of physics are not just about scientific facts and methods. Even though it is seldom mentioned in the textbooks, attitudes and values are created and recreated in the classroom. The physics teaching for future physics teachers is dominated by a traditional view of the science of physics, which is likely to influence their teaching and view of the educational subject. Thereby, the notion of physics as a science for an elite rather than for everyone, risks being reproduced. As this study shows, new teaching methods is no universal remedy for this. New teaching methods do not necessarily lead to new values.

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REFERENCES

Aikenhead, G. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27*(1), 1-52. https://doi.org/10.1080/03057269608560077

Aikenhead, G. (2006). *Science education for everyday life. Evidence-based practice*. Teachers College Press.

Angell, C., Guttersrud, Ø., Henriksen, E. K., & Isnes, A. (2004). Physics: Frightful, but fun. Pupils' and teachers' view of physics and physics teaching. *Science Education, 88*, 683-706. https://doi.org/10.1002/sce.10141

Börjesson, M., Broady, D., Le Roux, B., Lidegran, I., & Palme, M. (2016). Cultural capital in the elite subfield of Swedish higher education. *Poetics, 56*, 15-34. https://doi.org/10.1016/j.poetic.2016.02.004

Bourdieu, P. (1977). *Outline of a theory of practice*. Cambridge University Press. https://doi.org/10.1017/CBO9780511812507

Bourdieu, P. (1984). *Distinction: A social critique of the judgement of taste*. Harvard University Press.

Bourdieu, P. (1996). *The state nobility. Elite schools in the field of power*. Blackwell & Polity Press. https://doi.org/10.1515/9781503615427

Bourdieu, P. (2000). Konstens regler: Det litterära fältets uppkomst och struktur [Tricks of the trade: The emergence and structure of the literary field]. In *Proceedings of Brutus Östlings*.

Bourdieu, P. (2004). *Science of science and reflexivity*. The University of Chicago Press.

Bourdieu, P. (2005). *Udkast til en praksisteori–indledt af Tre studier i kabylsk etnologi* [*Sketch for a theory of practice. Introduction to three studies in Kabyle ethnology*]. Hans Reitzels Forlag.

Bourdieu, P., & Passeron, J.-C. (1979). *The inheritors. French students and their relation to culture*. The University of Chicago Press.

Bourdieu, P., & Passeron, J.-C. (1990). *Reproduction in education, society and culture*. Sage Publications.

Bourdieu, P., & Passeron, J.-C. (2008). *Reproduktionen. Bidrag till en teori om utbildningssystemet* [*Reproduction. A contribution to a theory about the educational system*]. Arkiv förlag.

Bourdieu, P., de Saint Martin, M., & Passeron, J.-C. (1994). *Academic discourse: Linguistic misunderstanding and professional power*. Polity Press.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Carlhed, C. (2011). Fält, habitus och kapital som kompletterande redskap i professionsforskning [Field, habitus and capital as supplementary tools in research on profession]. *Socialvetenskaplig Tidskrift* [*Journal of Social Sciences*]*, 18*(4), 283-300. https://doi.org/10.3384/SVT.2011.18.4.2462

Carlone, H. B. (2004). The cultural production of science in reform-based physics: Girls' access, participation, and resistance. *Journal of Research in Science Teaching, 41*(4), 392-414. https://doi.org/10.1002/tea.20006

Duit, R. (2014). Teaching and learning the physics energy concept. In R. F. Chen, A. Eisenkraft, D. Fortus, J. Krajcik, K. Neumann, J. Nordine, & A. Scheff (Eds.), *Teaching and learning of energy in K-12 education* (pp. 67-85). Springer. https://doi.org/10.1007/978-3-319-05017-1_5

Engström, S. (2011). *Att vördsamt värdesätta eller tryggt trotsa. Gymnasiefysiken, undervisningstraditioner och fysiklärares olika strategier för energiundervisning* [To humbly value or safely defy. Upper secondary school physics, traditions in teaching and physics teachers' strategies for teaching energy] [Doctoral dissertation, Mälardalen University, Sweden]. Mälardalen University Press dissertations 100.

Engström, S., & Carlhed, C. (2014). Different habitus – different strategies in teaching physics? Relationships between teachers' social, economic and cultural capital and strategies in teaching physics in upper secondary school. *Cultural Studies of Science Education, 9*(3), 699-728. https://doi.org/10.1007/s11422-013-9538-z

Harding, S. (1991). *Whose science? Whose knowledge? Thinking from women's lives*. Cornell University Press.

Harding, S. (2006). *Science and social inequality. Feminist and postcolonial issues. Race and gender in science studies*. University of Illinois Press.

Hasse, C. (2002). Gender diversity in play with physics: The problem of premises for participation in activities. *Mind, Culture, and Activity, 9*(4), 250-269. https://doi.org/10.1207/S15327884MCA0904_02

Höttecke, D. Henke, A., & Riess, F. (2012). Implementing history and philosophy in science teaching: Strategies, methods, results and experiences from the European HIPST project. *Science and Education, 21*(9), 1233-1261. https://doi.org/10.1007/s11191-010-9330-3

Johansson, A. (2015). *Uniformity in physics courses and student diversity: A study of learning to participate in physics* [Licentiate thesis, Uppsala University].

Johansson, A. (2018). *The formation of successful physics students: Discourse and identity perspectives on university physics* [Doctoral dissertation, Uppsala University].

Keller, E. F. (1992). *Secrets of life, secrets of death*. Routledge.

Lemke, J. (1990). *Talking science: Language, learning and values. Language and educational processes*. Ablex Publishing.

Lemke, J. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching, 38*(3), 296-316. https://doi.org/10.1002/1098-2736(200103)38:3<296::AID-TEA1007>3.0.CO;2-R

Lemke, J. (2011). The secret identity of science education: Masculine and politically conservative? *Cultural Studies of Science Education, 6*, 287-292. https://doi.org/10.1007/s11422-011-9326-6

Lövheim, D. (2006). *Att inteckna framtiden–Läroplansdebatter gällande naturvetenskap, matematik och teknik i svenska allmänna läroverk 1900-1965* [*Securing the future: Curriculum debates concerning science, mathematics and technology in Swedish secondary schools 1900-1965*] [Doctoral dissertation, Uppsala University].

Roth, W.-M., & Lee, S. (2002). Scientific literacy as collective praxis. *Public Understanding of Science, 11*(1), 33-56. https://doi.org/10.1088/0963-6625/11/1/302

Swedish Research Council. (2017). Good research practice. *Swedish Research Council*. https://www.vr.se/download/18.5639980c162791bbfe697882/1555334908942/Good-Research-Practice_VR_2017.pdf

Tobin, K. (2009). Difference as a resource for learning and enhancing science education. *Cultural Studies of Science Education, 4*(4), 755-760. https://doi.org/10.1007/s11422-009-9241-2

Van Eijck, M. (2013). Reflexivity and diversity in science education research in Europe: Towards cultural perspectives. In N. Mansour, R. Wegerif, C. Milne, C. Siry, & M. P. Mueller (Eds.), *Science education for diversity, cultural studies of science education* (pp. 65-78). Springer. https://doi.org/10.1007/978-94-007-4563-6_4

Webb, S., Burke, P. J., Nichols, S., Roberts, S., Stahl, G., Threadgold, S., & Wilkinson, J. (2017). Thinking with and beyond Bourdieu in widening higher education participation. *Studies in Continuing Education, 39*(2), 138-160. https://doi.org/10.1080/0158037X.2017.1302926