Quantum physics, history, philosophy and NoS in traditional physics classrooms

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Abstract

History, philosophy and the nature of science (NoS) are advocated as important elements of science education. Quantum physics has been shown to motivate physics students due to its philosophical aspects, making the topic suited for learning activities that foster understanding of NoS and of the history and philosophy of physics. This paper discusses experiences from teaching senior high school quantum physics through such learning activities. Web-based teaching modules let students explore quantum physics through collaborative learning and historical and philosophical contexts. Data consists of seven focus groups with in total 40 participants from seven physics classrooms and one focus group with five teachers. Data were collected in 2014-2015 and analyzed qualitatively using a thematic approach, focusing on history, philosophy, NoS, motivation and physics classroom culture. Although students were motivated by physics history and philosophy, their recognition of these aspects and NoS as knowledge in its own right appears to have been limited by their enculturation into a traditional physics classroom oriented towards content knowledge, assessment and exams rather than physics history, context and processes. We suggest that physics history, philosophy and NoS learning goals and assessment criteria should be made more explicit to students, and assessment tools developed for teachers and exam developers.

Introduction

Understanding of the history, philosophy and nature of science (NoS) has long been advocated as an important element in science education (Abd-El-Khalick, 2013; Monk & Osborne, 1997). This is also reflected in curriculum documents such as the Next Generation Science Standards (NGSS, 2013). The Norwegian national curriculum for the optional physics subject for the final year of high school aims to help students “create an awareness that physics is part of our cultural heritage and that the subject must be viewed in a historical perspective” and strengthen their “ability to differentiate between scientifically-based knowledge and knowledge not based on scientific methods” (NDET, 2006). Quantum physics has been shown to motivate Norwegian physics students due to its philosophical aspects (Angell, Guttersrud, Henriksen, & Isnes, 2004), making the topic well suited as a starting point for implementing teaching and learning activities that foster understanding of NoS and of the historical and philosophical aspects of physics. This is also in accordance with learning goals in the Norwegian physics curriculum, which states for instance that students should be able to “give a qualitative account of how results from experiments with photoelectric effect, Compton scattering and the wave nature of particles represent a break with classical physics” and to “give an account of Heisenberg’s uncertainty relations, describe the phenomenon ‘entangled photons’ and give an account of their epistemological consequences” (NDET, 2006).
Such aims are in line with calls for physics education to move beyond the traditional content-focused physics classroom culture and include historical, epistemological and sociocultural aspects (see e.g. Duit, Schecker, Höttecke, & Niedderer, 2014). However, there exists a strong disciplinary culture within physics teaching which tends to emphasize physics content and basic laws rather than physics history, contexts and processes. Carlone (2003) described the challenges involved in implementing a reformed physics course within a culture focused on achievement and with clear expectations for what counted as a “real physics” course. Höttecke and Silva (2011) identified several obstacles to teaching history and philosophy of physics, namely the culture of teaching physics, teachers’ skills and attitudes, institutional framework, and textbooks. Many of these were seen in a study by Henke and Höttecke (2015) of history and philosophy of physics project in German middle schools. This study also observed resistance to the approach and decreased motivation from many students.

The present paper reports results from project ReleQuant (see Henriksen et al., 2014), which develops web-based teaching modules for relativity and quantum physics that emphasize conceptual understanding, history and philosophy of physics, understanding of NoS, and student motivation (http://www.mn.uio.no/fysikk/english/research/projects/relequant/). Although the ReleQuant modules are web-based, they invite learners to develop their understanding through interaction with others – in particular through the use of language – and emphasize knowledge in physics as a human product. The ReleQuant modules hence provide an opportunity to study the challenges identified by Höttecke and Silva (2011) from a student perspective in addition to the teachers’ perspective. In this paper we ask:

*How is the traditional physics classroom manifested and challenged through physics students’ and teachers’ work with teaching modules in modern physics emphasizing historical and philosophical aspects and NoS?*

An example of the material is briefly presented as follows: The first teaching module in quantum physics is called *Need for new physics*, and uses the nature of light as a starting point for working with the development of quantum physics and how it constitutes a break with classical physics. The students start with answering the question “What do you think light is?” in writing, based on their previous knowledge. After this follows a short animation film about the development of quantum physics, focusing especially on the nature of light, Einstein’s work on the photoelectric effect and his light quant hypothesis and Niels Bohr’s opposition. The film ends up stating that we still have two models for light, the particle model and the wave model, and that physics in general is unfinished. Another film follows, where physicists at the University of Oslo answer the question “What is light?” in quite different ways. The theoretical physicist explains it from a typical wave-particle duality perspective, primarily advocating the particle model. The other physicist sticks to the wave model, and explains how he is critical to the wave-particle duality in quantum physics, and points to, for example, the paradox in that a point particle can have a wavelength. The students are then asked to discuss in pairs the question “Can a particle have a wavelength?” (Figure 1) They record the discussions on their smart phones and send the file to their teacher. When they are done, they see another short film where the same two physicists talk briefly about how their differences of opinion boil down to interpretations of quantum physics and philosophical points of view.
Methods
ReleQuant employs an educational design research methodology (EDR, also referred to as design-based research), as it addresses educational problems in real-world settings with two primary goals: to develop knowledge and to develop solutions (Reeves & McKenney, 2012). Physics educators, physicists and teachers develop the learning modules collaboratively, to assure material that is research based, theoretically sound and adjusted to students’ and teachers’ needs. Learning modules are developed and classroom data collected in several cycles. The current study uses qualitative data from the first three rounds of classroom data collection. A total of 40 students and five teachers participated in eight focus groups, one student group from each of seven senior high school physics classes (students aged 18-19) in four high-performing schools in suburban areas in Norway, and one group with five physics teachers from these schools. The students worked with the ReleQuant quantum physics modules as part of their regular physics education. The teachers were well familiarized with the ReleQuant material prior to using it. The focus groups were conducted after the students had completed their work with the teaching modules, using an interview guide based on classroom observations, teacher interviews, and previous research. Major discussion themes concerned how working with the ReleQuant modules had influenced students’ learning, motivation and epistemological
reflections. The teacher interview guide was based in part on findings from the student interviews. It focused on experiences from and expectations for teaching with ReleQuant, using language, history and philosophy, NoS, and on student outcomes and assessment. Audio recordings of the interviews were transcribed, and coded based on thematic analysis (Braun & Clarke, 2006), resulting in themes and sub-themes such as “history, philosophy and NoS”, “motivation”, “traditional physics classroom”, “visualization”, “variation”, “learning” and “achievement and assessment”. Patterns in the themes are presented through illustrative quotes in the next section. Quotes are indicated with S for student and T for teacher.

**Results**

History, philosophy and NoS aspects were generally described as motivating. Concerning learning about the history of quantum mechanics, one student said:

*S: I liked that you included some history too, like Einstein and Bohr and the great physicists. A bit of where it comes from. It’s interesting to […] like hear a bit about that too.*

*S: It’s confusing because it goes against much of what we have learnt, but […] when there are things we can’t quite explain it is very exiting and you sort of want to try and find out for yourself.*

However, such aspects were rarely recognized as learning goals in themselves, illustrated with these quotes about historical aspects:

*S: It can be ok – although we may not learn more physics – that we know a bit about where it came from.*

*S: I don’t think it should be important on tests. That in a way it is more background information.*

The focus group with the teachers corroborated the impression from the students. They admitted that they rarely used historical or philosophical aspects in their physics teaching, and mostly in an anecdotal, motivational manner. Nevertheless, several teachers argued that such aspects are important, and expressed a wish to be able to use it more. They pointed to time constraints and lack of text book material as reasons for not using history of physics more in their teaching.

The focus groups with both students and teachers suggested that they were used to a traditional physics classroom, and that ReleQuant for the most part was regarded as a positive variation.

*S: It’s very different, […] that you’re supposed to formulate and explain things instead of doing calculations, we’re not used to that. It’s a totally different way of learning, really.*

However, traditional teaching involves mainly teacher-led instruction and solving of factual problems usually involving calculations. And this practice seemed to be an obstacle to successful inclusion of history, philosophy and NoS aspects, in particular in terms of achievement and assessment. The lack of “right or wrong”-answers or an answer-key (list of correct answers) appeared to deprive the students of a well-known way of confirming that they had learnt something and done well:

*S: Yeah, yeah, [quantum physics] is proper physics, but it doesn’t have that much calculations and stuff. So it’s hard to demonstrate knowledge.*
S: There should be an answer key on those written tasks. Doing tasks without an answer key gives us nothing.

This resonates with challenges expressed by the teachers concerning assessment of the students’ written and oral responses to questions in the teaching modules. Giving feedback to qualitative questions is difficult, one teacher said while expressing concern that the students’ learning would suffer as a result. At the same time, the teachers saw great potential in using students’ written and oral responses when preparing their lessons, and even in developing themselves as teachers:

T: A motivation for me at least is that I learn more about what the students actually learn. [...] By learning about my students’ learning I can change my teaching.

The students in the focus groups also expressed concerns about assessment and exams:

S: What if you’re having a test, and you write something about photons, for example. Then the teacher can’t know if you’re right, so how can they score the test?

S: Thinking about exams and stuff, [...], I don’t think [quantum physics] is that relevant. But at the same time I think it’s an interesting part of physics that is good.

End exams and time constraints were major themes in the teacher focus group data. According to the teachers, quantum physics has not been emphasized in recent national exams in secondary physics, making it difficult to prioritize the topic within a large and time consuming curriculum. The teachers expressed an obligation to their students’ exam results that rivaled, and for some even outweighed, their obligation to the national curriculum. Two teachers expressed it like this:

T: What dictates us is what the exam looks like. [...] We want our students to achieve as good a grade as possible. [...] I think that some of the [ReleQuant modules] maybe exceed what is expected in the exam. I can use this much time on it, but then I have to cut back on something else. So there’s a priority to make.

T: I think it is really great to be part of [the ReleQuant project], it has really done something with how I think about being a teacher, but ... I am sitting there with a knot in the pit of my stomach when I look at the exam problems.

Discussion

This paper presented results from focus group discussions with senior high school students who had been taught quantum physics through an approach emphasizing history and philosophy of physics, NoS, and collaborative learning, and from a focus group with their teachers. The data suggest that the obstacles to learning about the history and philosophy of physics described by Höttecke and Silva (2011) could be recognized not only from the teachers’ perspective, but also in discussions among the students. Being used to a traditional physics classroom, dominated by focus on factual content knowledge, individual problem solving, correct answers and traditional assessment practices, both students and teachers saw ReleQuant as a positive variation, for the most part. History, philosophy and NoS aspects were generally viewed as motivating, though rarely recognized as learning goals in themselves. The largest obstacle to successful implementation of history, philosophy and NoS aspects appeared to be assessment practices, exams and time constraints. It appeared important to students to be able to achieve in the way they were used to, and be able to confirm that they had performed a task correctly. Some of them
missed traditional problem solving, seemingly because this usually was a way to make sure they would do well on tests. It is also possible that deviance from their traditional ways of achieving made it more difficult for the students to maintain their physics related self-concepts.

Although this study reinforces many of the findings of similar reform-based physics projects (Carlone, 2003; Henke & Höttingecke, 2015; Höttingecke & Silva, 2011), it deviates in some aspects. Contrary to the experiences of Henke and Höttingecke (2014), for example, both students and teachers expressed that the ReleQuant modules were motivating, and the analyses reveal that the history, philosophy and NoS aspects contributed to this. Moreover, quantum physics as a topic is generally viewed as more interesting and motivating by students than classical physics (Angell, Guttersrud, Henriksen, & Isnes, 2004). The modules are web-based, and the students commented on this as a welcome variation that was motivating. Moreover, the web-based nature of the modules and the digital storage of all student responses, both written and oral, offer new possibilities for assessment practices. Other clear differences from the studies by Carlone (2003) and Henke and Höttingecke (2015), are that ReleQuant reports from a Norwegian school context, the topic is quantum physics, and the students are in their final year of senior high school, which likely explains the emphasis both students and teachers put on achievement, assessment and exams.

The teaching modules try to do a lot at the same time: teach physics content and processes, develop skills in writing and talking physics, visualize subatomic physical phenomena, and promote epistemological reflections on quantum physics. The focus groups suggest that both teachers and students have focused more on the content knowledge competence aims more than aims concerning history, philosophy or NoS, in line with previous research (Duit et al., 2014). Monk and Osborne (1997, p. 411) suggested that small changes in existing curricula should be used as “a Trojan horse to achieve some of the broader aims” of history and philosophy of science teaching. Although this has been done in the current Norwegian physics curriculum, the focus group data reported here demonstrate that this is not enough. The Norwegian physics curriculum goes far in introducing NoS and historical and philosophical learning goals, but assessment forms, student and teacher attitudes do not appear to follow suit. As long as teachers feel that their primary obligation is to their students’ exam results rather than the national curriculum, and they believe that physics exams to a very little extent emphasize historical or philosophical aspects, or even qualitatively formulated content knowledge goals, the Trojan horse will not have much impact even inside the national curriculum fortress.

The results demonstrate from a Norwegian senior high school level how innovative approaches meet resistance in traditional physics classrooms, despite the fact that students and teachers may be motivated by the new approach. The results indicate that history, philosophy and NoS learning goals should be made more explicit to students and teachers. Thus, for the next cycle of ReleQuant classroom trials, we have added an introductory section labeled “Learning with ReleQuant”, describing how students are expected to work with the materials, and that they include learning goals concerning the processes of physics and NoS. For instance it explains that the material requires them to discuss physics questions that have no definite answers. We have also made changes to the material to bring history, philosophy and NoS aspects to the front more clearly. These changes will be studied further in the ReleQuant project. Further, tools and guidelines for assessing such learning goals should be developed and made available to teachers and national exam developers, and ongoing work in ReleQuant investigates how and to which
extent national exams test students’ understanding of historical, philosophical and NOS aspects. More research is needed on how classroom culture as well as teaching, learning and assessment practices may be developed to meet aims for a broader and more modern physics education.

References