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How high schools teach quantum physics – a cross-national analysis of curricula in secondary education

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Abstract. Quantum physics (QP) changed our worldview, it brought us modern electronic devices, and its almost mythical image fascinates. Although QP is relatively new in secondary education, it is now part of the national curricula of many countries. To understand the current state of QP content in high schools, we scrutinised upper secondary school physics curriculum documents in 15 countries. In these countries, we identified a similar core curriculum of QP which contains the following seven main categories: discrete atomic energy levels, interactions between light and matter, wave-particle duality, de Broglie wavelength, technical applications, Heisenberg's uncertainty principle, and the probabilistic nature of QP. We also found differences in the focus of the listed topics of individual countries, which indicate different views on teaching QP. The thematic focus of QP items is related to the underlying goal of science education and to the way students' knowledge is tested. This overview shows which QP content is generally feasible at a secondary level and which pedagogical perspectives are possible. Therefore this study might lead to reflections on existing QP curricula, and inspire countries that do not have QP in their curriculum yet.

1. Introduction

QP is a compulsory topic in the pre-university curriculum of many countries. There are several reasons to introduce 16-18-year olds to this part of modern physics: it should give them a recent image of physics, and QP is fundamental to devices students know from their daily lives, like semiconductors (mobile phones), lasers or solar panels. Additionally, the fascinating 'weirdness' can be motivating for students [1].

However, literature reports that teaching QP in secondary schools (or to non-physics majors) is challenging: Students have limited mathematical backgrounds, QP phenomena do not align with students' classical physical knowledge, and teachers might not sufficiently master the subject for teaching [2]. Therefore, many different ideas have been proposed about introducing QP to high school students (e.g.: [3--5]). Recent research shows that epistemological aspects can motivate and help students to engage in relevant discussions about QP concepts [6]. Additionally, addressing different interpretations of QP offers opportunities to teach about the Nature of Science (NOS) [7--9]. The following NOS aspects appear to be relevant in QP teaching: methodologies, scientific models, tentativeness, creativity and controversies in science, often presented in a historical context.

While a few countries have a tradition of 50 years of QP teaching, some introduced it only recently into the upper secondary physics curriculum. In other countries, curriculum makers consider the possibility to introduce conceptual QP at the pre-university level. In this situation, it is useful to analyse and compare existing QP curricula in secondary school from different countries. In this study, we collected sources describing QP curricula in 15 different countries [8]. The guiding questions of our study are:

(1) Which QP topics are included in upper secondary school physics curricula of different countries?
(2) What are the similarities and the differences between the content of QP in these curricula?
(3) How is QP placed in a perspective of learning about NOS in different countries?

2. Method

We collected official upper secondary physics curriculum documents, legislated on national or federal level, from the following countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany (documents of 7 states), Italy, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom (England and Scotland). As our search for QP curricula was guided by published physics education research in English, the research is limited to these 15 countries. Information on QP curricula from other countries was not available.

Comparing the curricula was complicated because different countries have varying ways to express teaching objectives. For example, in the Netherlands, where students must take high-stakes exams on the subject, education requirements are spelt out in great detail. In countries where the subject is optional, descriptions of the curricula are presented in a more general way.

Subsequently, we identified QP concepts and NOS aspects in these documents and categorised the curriculum items to make a comparison. We then identified items that occurred in the documents of all countries to define the current core curriculum. For the additional items, we distinguished different foci of QP teaching in diverse countries. Finally, we collected general information about each school system to relate educational traditions and test practices to specific QP content. A systematic overview of these boundary conditions of each educational system and a complete reference list to all original curriculum documents can be found in reference [8]. Our analyses were validated by physics education experts in the respective countries.

3. Results

3.1. Core curriculum

We found that seven QP items are present in all 15 curriculum documents [8]. Most items in this common core curriculum are Fundamental QP principles, phenomena and applications, see figure 1. This figure also shows additional items that were found in the curricula of some countries.

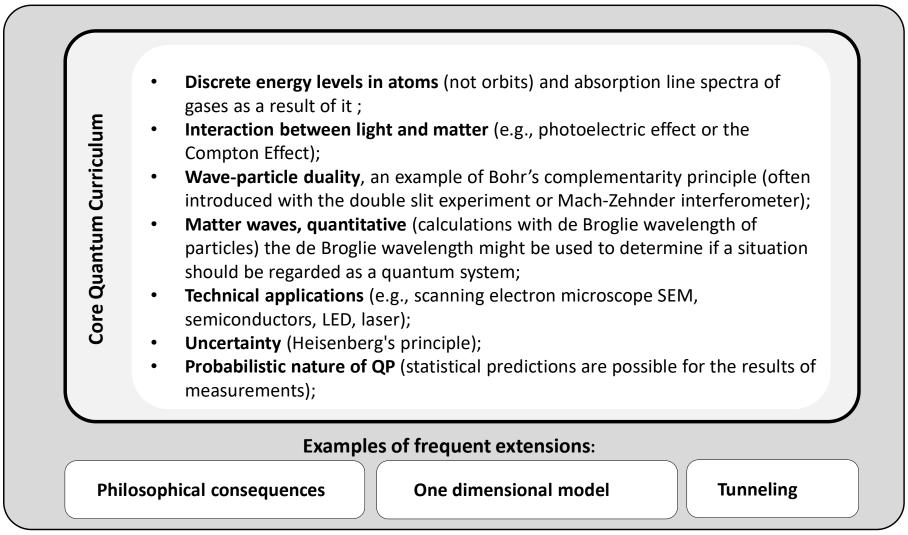

Figure 1. Core Curriculum and extensions (adapted from [8]).

3.2. Focus on different aspects of the extra items

Curriculum items that were not part of the core curriculum all fall in one of the following three categories: (1) Atomic theory, (2) Wave function or other mathematical representations or (3) Philosophical aspects of QP. The content of curricula from countries that teach more than the core curriculum focus on one or more of these themes, as shown in figure 2. Especially the curricula that form the basis for standardised final exams focus on mathematical representations.

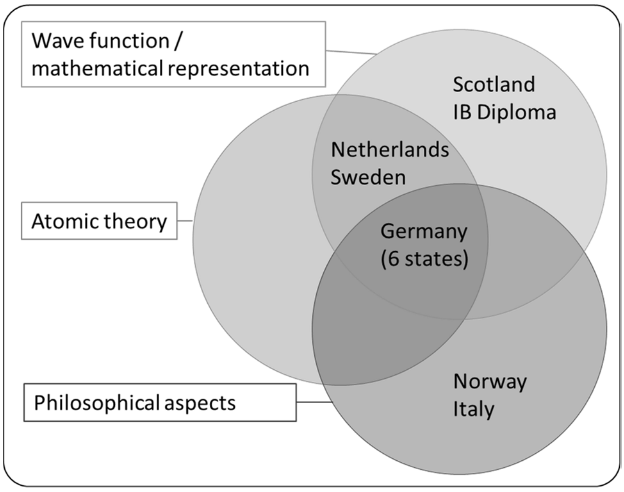

Figure 2. Curriculum Focus of different countries (adapted from [8]).

4. Discussion

The fact that we were able to find commonality in QP topics in the curricula of 15 different countries shows that certain QP concepts are established elements of upper secondary physics education. These items together form a core curriculum which can be seen as the status quo of secondary QP education, especially in Europe.

The choice for additional QP items in secondary education depends not only on the practical constraints, like lesson time or teacher knowledge but also on the goals of upper secondary physics education in general. If preparing future physicists and engineers is the primary goal of a course, more mathematical representations and connections to other fields of science should be chosen. If, on the other hand, a course aims to develop scientific literacy, the philosophical and historical aspect of QP should get more attention in physics classrooms. We see many possibilities to relate NOS concepts to this context and found promising new teaching approaches in this direction in Norway and Australia [10,11].

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