Acceptance of Dirac-Notation by high school students

Gesche Pospiech

Faculty of Physics, Physics Education Research, TU Dresden, Haeckelstraße 3, 01069 Dresden, Germany

Abstract. Quantum physics recently gains greatly in attention in school education. The central question is to which extent it can, cannot or even has to be taught with formal mathematical means. In the context of two-state-approaches the use of Dirac-notation seems an adequate possibility. Therefore we present an approach for high school using Dirac-Notation that was applied in an exploratory study analysing the acceptance of Dirac-notation by high school students. This study gives promising results if the some basic mathematics skills are properly addressed.

1 Introduction

Quantum information and quantum technology nowadays gain increasingly importance. This development leads to new ways in teaching quantum physics [1]. Especially two state systems are being used in this context as these are not only important in understanding quantum information but can also serve as an appropriate toy system to teach the basic concepts of quantum physics including mathematical tools [2]. Moreover it becomes apparent that in treating topics from quantum information such as the non-cloning-theorem a purely qualitative description of the processes is not sufficient. Hence formal means such as the Dirac-notation seem to have to be adopted also in high school. In addition students can learn in this way about the nature of physics in connecting physics concepts with formalization, making predictions and gaining advanced insights. An advantage of the Dirac-notation is that it can be used very flexibly, with visual symbols supporting to recognize the relation between physics objects or concepts and the mathematical calculation.

2 Research Question

Depsite the importance of the Dirac-notation and its frequent use in physics and even in physics education [3] there are few systematic evaluations concerning in which way high school students would understand and use the Dirac-notation. Therefor we developed and evaluated an approach probing in a teaching experiment the acceptance of Dirac-notation by high school students. The research question concerned:

- How would students cope with the Dirac-notation and master its use?
- Do they accept it as a useful means for describing quantum physics objects?

3 Methods

In order to get hints concerning the possible problems and possibilities of the Dirac-notation a qualitative approach was chosen. A teaching-learning sequence was designed and tested in teaching experiments with high school students (N = 7) [4].

The sequence was constructed in drawing on research concerning different representations of mathematical structures (algebraic, numerical, graphical, symbolic) [5] and on connecting the principles of superposition and uncertainty with the mathematical structures. Among the visualisations the “Bloch circle” plays a central role.

The instruction lasted 2,5 hours and was divided in five thematic sections: quantum states, superposition, measuring process, probabilities, application to quantum cryptography. In each section the students first received an instruction with help of a powerpoint presentation and oral explanations. After this they interacted with the instructor by asking questions, summarizing in own words what they learned and if they found the explanations logical and helpful. Then they were given problems to solve in order that the instructor could see which aspects had been understood and where the students showed problems.

In the teaching experiments students from grades 10 and 11 took part voluntarily. The sessions were audiotaped and transcribed. The students’ written notes were kept.

In the qualitative evaluation of the transcripts several categories were formed inductively from the data: technical-mathematical aspects (formal knowledge), structural aspects with focus on mathematics, structural aspects with focus on physics, acceptance of visualizations and interest in quantum cryptography. Each of these categories had four steps of mastering: (1) no understanding or understanding only after several explanations, (2) problems with application or formulating, (3) no or only slight difficulties, (4) mastering and in depth conceptual thinking. The naming “steps of mastering” indicates that a student could show all the steps during the teaching experiment, separately in each thematic section.

4 Results

Mostly the students could cope quite well. All the students with one exception showed elements of step 3 of mastering in all categories. But often step 2 (difficulties with own verbalization) was observed. Only one student showed severe difficulties with some technical aspects. One student was strong on the technical aspects and structural aspects with focus on mathematics, reaching step 4. Three students reached step 4 on structural aspects with focus on physics. Three students achieved step 4 with the visualizations. On the whole the students showed a good acceptance with difficulties mostly concerning elementary rules from mathematics or interference between the Bloch circle and the vector concept in mathematics. However, the conceptual aspects of quantum physics and interest in quantum cryptography were quite good. This qualitative study can only give some hints but shows promising results for treating aspects of quantum information with help of Dirac-notation at high school.

References

1 Sadaghiani, HR Spin First vs. Position First instructional approaches to teaching introductory quantum mechanics. In: Physics Education Research Conference Proceedings (Compadre), pp 292–295.

2 Pospiech G. Teaching the EPR paradox at high school? Physics Education. 1999;34(5):311.

3 Weissman EY, Merzel A, Katz N, Galili I. Teaching quantum physics as a structured physics theory in high school. Journal of Physics: Conference Series. 1. Mai 2021;1929(1):012051.

4 Müller, C Planung einer Unterrichtseinheit zur Quantenkryptografie und Akzeptanzanalyse der Dirac-Notation. Wissenschaftliche Hausarbeit, TU Dresden.

5 Geyer M-A, Kuske-Janßen W. Mathematical Representations in Physics Lessons. In: Pospiech G, Michelini M, Eylon B-S, eds. Mathematics in Physics Education. Cham: Springer International Publishing; 2019 p 75–102. http://link.springer.com/10.1007/978-3-030-04627-9_4