From Quantum Optical Experiment to Description Using Dirac Notation in Physics Classrooms - Results of an Acceptance Survey

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Abstract. According to the curricular changes, quantum physics is going to be given more importance in teaching Physics in secondary schools. The quantum object photon is introduced and discussed. A further study will investigate whether a reduced mathematical formalism can enhance students' understanding of the concept. The instructional elements of the learning sequences developed for this purpose have been tested on a pilot basis and the results are presented here.

Introduction

Learning about quantum physics (QP) can be challenging for both young people and adults in formal and informal education. Physics education research continues to focus on these learning difficulties in the field of QP [1]. Previous empirical research has shown that a conceptual understanding of the photon is positively correlated with a functional understanding of models [2]. Therefore, promoting a functional understanding of models can be considered a goal of QP lessons. However, specific measures for achieving this goal have not yet been explored and evaluated.

Previous research

A mental model is the conscious representation of an object or a physical process. Ubben previously investigated learners' mental models of the atomic shell and explained the variance in study results using a two-factor structure: The author refer to these two factors as Gestalt fidelity and functional fidelity [3]. Ubben and Bitzenbauer conducted empirical research that revealed learners' mental models of the quantum object photon are described with a two-factor structure [4] and the concept understanding is positively correlated with a functional model. Therefore, promoting functional conceptions of the photon model should be an aim of quantum physics teaching. Previous physics education research has not investigated how to promote a functional understanding of the model. Numerous empirical studies have examined the impact of introducing mathematical formalism on learners’ comprehension, e.g. [5].
An abstract mathematical formalism cannot be interpreted formally, but it can promote a functional understanding of the model. A learning sequence has been developed that uses GeoGebra animations and interactive screen experiments to clarify selected photon properties qualitatively and make the reduced Dirac formalism accessible.

Research Questions

With regard to the further development of the instructional elements and the exploration of possible pre-concepts, the following research questions can be formulated.

1. To what extend do students accept the individual instructional elements with regard to the underlying key concept?
2. What learning difficulties can be identified after instruction?
3. Based on these findings, what are the implications for the further development of the instructional elements?

Methods

The study's learning sequence was divided into six key concepts: the phase of an electromagnetic wave, interference of electromagnetic waves, anticorrelated measurements of photon states, introduction of a reduced Dirac formalism, single photon interference in a Michelson interferometer, and mathematical description of single photon interference.
To answer the research questions, guided individual interviews were conducted with 14 students from a heterogeneous group of undergraduates. The interviews followed a regular sequence of instruction, acceptance questions, rewriting, and application tasks. This procedure not only provided feedback from experienced learners but also allowed us to gain insights into the various difficulties experienced by the learners. The answers provided by the students were categorized into a three-level ordinal-scaled category system using qualitative content analysis. Additionally, the pre-concepts of the test subjects were categorized using inductive category formation according to Mayring.

Results

The analysis of the data showed that the participants accepted the elements of the instruction and were able to paraphrase the content successfully. One participant even paraphrased all learning sequences correctly. When evaluating the application task, the participants showed varying preconceptions regarding the key concepts. Regarding quantum physics, learners often have misconceptions about particles, locality, and simultaneity.
The learners' responses indicate a need for adaptation of instructional elements.

References

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