Identifying student interpretations of quantum mechanics in upper tertiary education

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Abstract. Despite quantum mechanics' significant role in technological advancements, its interpretations remain a subject of ongoing debate among scientists. In this study we examine the evolution of student perspectives on quantum mechanics interpretations during an elective course on the subject in upper tertiary education. We focus on identifying changes in student thinking and developing an instrument for teachers and students to examine their own views on various aspects of interpretations of quantum mechanics, such as realism and locality. In this presentation we present our preliminary findings.

Introduction

In teaching quantum mechanics (QM), teachers often focus on the mathematical formalism of the theory, e.g., solving the Schrödinger equation. Such calculations allow us to make excellent predictions of experimental outcomes and have led to a wealth of technological innovation. But what do these abstract mathematical constructs tell us about the nature of the world around us? Is a superposition of particle properties physically real or only an expression of our ignorance before measurement: can a particle be at two (or more) places at once, for instance? And what happens to these superposed states when they are detected?

Scientists and philosophers have constructed different answers to such questions. Similar answers are grouped under a so-called “interpretation of quantum mechanics” - such as the Copenhagen and Many Worlds interpretations [1]. Discussions on interpretations of QM have led to various new insights and experiments over the past 100 years, perhaps most notably so-called Bell tests [2] which was the subject of the 2022 Nobel Prize in physics. However, in teaching QM, the importance of acquiring mathematical skills regularly pushes questions of epistemic and ontological nature into the background, if only because currently there is no single right interpretation. This is strongly reflected in the *shut up and calculate* approach to QM, where the mathematical answer to a question is more important than its interpretation. However, research has shown that even when instructors take an agnostic stance regarding the interpretation of QM in their teaching, students will construct their own views on the meaning of the theory. When students are questioned more deeply about their ideas, they often end up in a cognitive conflict where they cannot describe everything from a single interpretation [3, 4]. Thus, we feel a discussion on interpreting QM deserves a place in education.

This study

Delft University of Technology offers an elective course as part of the master Applied Physics that focusses on interpretations of QM while maintaining a firm grip on its mathematical underpinnings. Students are expected to have completed various undergraduate QM related courses prior to attending the elective. During lectures, aspects of the theory, e.g., Bell’s inequality [5], are presented. Students and instructors thereafter exchange ideas with the instructors about the meaning and implications of these aspects. This exchange of ideas is often kickstarted by a disagreement about interpretation between the two main instructors of the course. The instructors firmly believe that such discussions with students will help them *think outside the box* which in turn may lead to new theoretical and technological discoveries in the future.

This study investigates whether and to what extent the approach used in the described elective is effective and encourages students to critically examine their own interpretations. The study revolves around three central questions:

1. How to identify student interpretations of quantum mechanics?
2. What changes occur in student interpretations during a course on the subject?
3. How can instructors promote a more investigative and critical approach in students when discussing these interpretations?

To answer these questions, we will sit in on the lectures, administer various questionnaires to students and use the outcome of these questionnaires to hold semi-structured interviews with a selection of students. We will use the data gathered to design and research the effect of one or more experimentally based interventions on student thinking. We are currently further developing our methodology and research tools and aim to apply these during the 2024 and 2025 iterations of the course, which are scheduled between April and July for both years. The goal is to develop an educational tool that instructors from more traditional QM courses, which focus more on mathematical rigor, can easily incorporate in their teaching in order to probe students' ontological and epistemological views of QM and consequently spark curiosity in students.

Presentation

During the 2024 WCPE conference we will share the first iteration of the research instruments that we have developed, as well as preliminary results with these instruments from the 2024 iteration of the course on interpretations of QM. Subsequently, we will look ahead to the 2025 course and discuss ways in which our preliminary findings may be used to design education that combines mathematical, experimental, and philosophical aspects of physical theories.

References

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