What is so difficult in quantum physics? Diagnosing high school students' difficulties in quantum physics

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Abstract. High school students learning quantum physics (QP) exhibit difficulties. In this Study, we investigate in-lesson interactions in the classroom, aiming at identifying these difficulties and their origin. Through the lens of combined categorization system from the literature, we used content and interaction analysis of videotaped lessons. We found difficulties in unexplored topics in QP education, and found that some of them originate in teacher-student interactions, while others result from previous teaching. Our results enrich teachers' pedagogical content knowledge for high school QP. They could be used for the design of learning materials and foster the creation of diagnostic tools.

Theoretical background

Due to its abstract nature and the departure from classical physics principles, students exhibit difficulties in learning QP in high school (HS) [e.g., 1]. Previous research on difficulties primarily relied on surveys, interviews, and problem-solving exercises to diagnose fundamental difficulties [e.g., 1,2,3]. The research looked into teacher-student(s) and student-student interactions in authentic lessons is rare, especially as a tool for identifying students' difficulties, although such tools exist [e.g., 4]. Additionally, research is scarce in identifying difficulties in some core topics in QP taught in HS, like superposition, wave-particle duality, entanglement and the double slit experiment. The educational context is a curriculum based on the Discipline-Culture (DC) approach [5].

Research questions

- What difficulties do HS students encounter while learning QP in the DC approach?
- What are the sources of these difficulties?
    - In what way do in-lesson interactions contribute to these difficulties or their reconciliations?

Methodology and analysis

We videotaped 30 hours (one-year course) of HS QP lessons designed in the DC approach taught for algebra-based 12th-grade students. We applied video analysis [e.g., 6] to selected episodes involving teacher-student(s) or student-student interactions [4]. We analyzed students' difficulties through content analysis based on a combined categorization system, derived from relevant research-literature [e.g., 7,8].

Findings

We mapped students' difficulties according to a combined categorization system (see Fig. 1) and found difficulties in QP topics that had never been described in the literature before. An example of this is the following example:

In a lesson concerning QP interpretations, the teacher draws analogies between the Double slit experiment and Schrödinger's cat experiment, in the context of the Copenhagen and Many Worlds interpretations. This leads a student to combine the two: "*But the Double slit experiment implies that there is a connection between the two 'splitted' worlds*". This difficulty occurs when learners' existing conceptual frameworks distort new information during interpretation, resulting in substantive learning impediments [as defined in 8]. These difficulties often stem from the use of

analogies [7]. Certain of these difficulties are interconnected and cannot be discerned through diagnostic surveys due to their intersubjective nature.

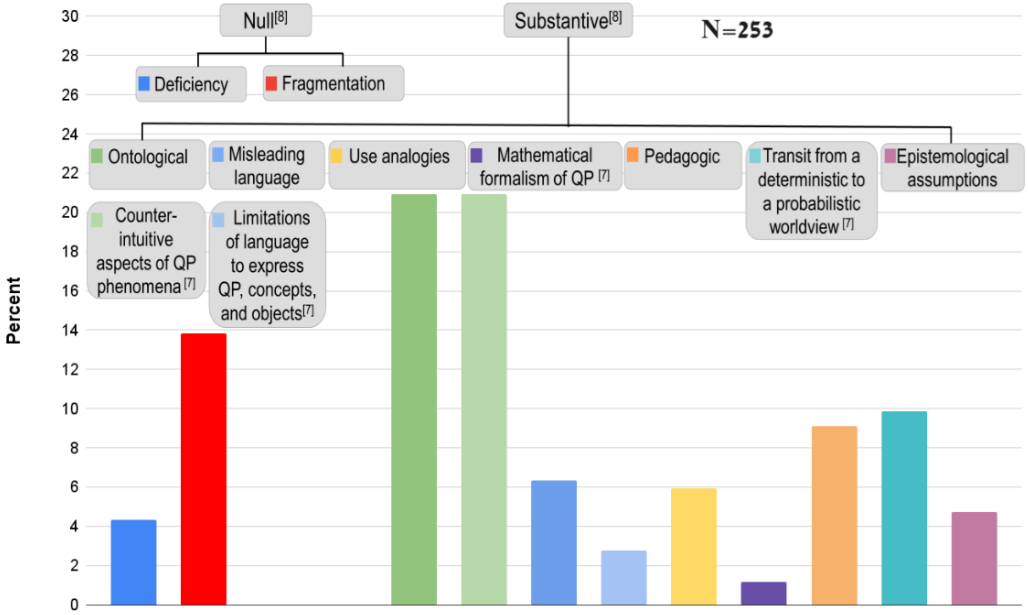

Fig. 1. Percentage of difficulties by the combined categorization system of learning impediments.

Conclusion

Validating the combined categorization system for students' impediments underscores the influence of teacher-student and student-student interactions, as well as prior teaching on student comprehension. Our findings emphasize the importance of enriching teachers' Pedagogical Content Knowledge about QP for HS students. Moreover, our research suggests practical applications in the design of tailored learning materials and the development of diagnostic tools to address students' misconceptions effectively.

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