Critical thinking in quantum physics learning: Development of a domain specific model

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Abstract. This study aims to develop a critical thinking (CT) model suited for pre-service physics teachers engaged in quantum physics learning. To achieve this, Halpern's Critical Thinking framework is used, due to its relevance to physics education and its focus on critical thinking skills applicable to quantum physics phenomena like probability, indistinguishability, uncertainty, superposition, measurement, entanglement, and spin. By developing this model, the development of teaching materials is facilitated, enabling the investigation of CT skill development in students. Viewing this model as an initial phase, the broader objective is to provide insights for enhancing teacher training programs in quantum physics.

Introduction

Quantum physics describes, correlates, and predicts the behavior of physical systems from particles through nuclei, atoms and radiation to molecules and condensed matter [1] and allows the development of new technologies. While up to now quantum physics education research was conducted mainly in undergraduate physics courses, recent efforts focus on quantum physics learning of high school students and content knowledge of pre- or in-service physics teachers [2-4]. Because quantum physics introduced new concepts different from classical physics such as indeterminism, probability, and non-locality [5], fundamental phenomena need to be carefully and critically thought through and careful use of language and of models is especially important during learning for full discrimination and comprehension.

Critical thinking (CT) involves evaluative and reflective analysis of thought processes and their outcomes [6]. To this end the skills of identifying accurate terminologies, drawing valid conclusions supported by reasons, controlling variables when testing hypothesis considering probability and uncertainty when predicting the occurrence of events, and making decisions and solving problems are particularly relevant to physics education [7].

Previous research addressing CT in physics education focused on developing materials and instructional designs for learning specific physics domains, such as particle physics [7]. However, the potential role of CT in learning quantum physics and its potential impact on the development of pre-service physics teachers' training programs was not yet investigated.

This study aims to address this gap by developing a CT model for teaching quantum physics and subsequently developing teaching materials. By investigating how pre-service physics teachers develop these CT skills and assessing whether these skills aid in comprehending quantum physics phenomena, the study seeks to inform teacher training programs.

Methodology

To develop a CT model in quantum physics, this study adopts Halpern' Critical Thinking framework [6], which encompasses skills such as verbal reasoning, argument analysis, thinking as hypothesis testing, likelihood and uncertainty analysis, and decision making and problem solving. Its relevance to physics education [7], particularly in addressing the skill of likelihood and uncertainty analysis, essential for understanding quantum physics, justifies its use. Combining the content knowledge relevant for pre-service physics teachers in their quantum physics course, including probability, indistinguishability, uncertainty, superposition, measurement, entanglement, and spin, with the Halpern CT skills defines domain-specific CT skills.

First proposals for CT Model in quantum physics

The described five CT skills must be operationalized for each phenomenon. As an example, table 1 refers to some examples of domain-specific CT skills in the context of indistinguishability, a property not known in classical physics but highly relevant for behaviour of quantum systems, so it allows students' discrimination of quantum physics from classical physics.

Table 1. Applying Halpern's Critical Thinking (CT) framework in indistinguishability context.

CT Skill	**Examples of domain-specific CT skills**
Verbal reasoning	Use language carefully in describing the double slit experiment (indistinguishability, path, slit, possibility)
Argument analysis	Argue with the concept of indistinguishability about possible outcomes of the double slit experiment in different variations (e. g. quantum eraser)
Hypothesis testing	Find out which outcomes of the double slit experiment can be expected classically and which with quantum objects
Likelihood and uncertainty analysis	Analyse how indistinguishability influences the calculation of probability (in the double slit experiment)
Decision making and problem solving	Determine how a double slit experiment has to be modified for getting an interference pattern with given visibility

Conclusion and Discussion

Developing a CT model for quantum physics learning and implementing it enables investigation into two main aspects. Firstly, it allows examination of how pre-service physics teachers develop CT skills, including identifying successful aspects and challenges. Secondly, it facilitates understanding of how the development of CT skills contributes to better comprehension of content knowledge. The findings derived from this investigation inform the development of pre-service physics teacher training programs.

References

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