A FRAMEWORK FOR DESCRIBING LEARNERS' MENTAL MODELS OF QUANTUM PHYSICS CONCEPTS

Philipp Bitzenbauer

Physics Education, Department of Physics, University of Erlangen, GERMANY

Abstract. In this contribution, we report on a questionnaire study conducted with 280 physics students into learners' mental models in QP in order to uncover the mental models' theoretical dimensions. Therefore, an established questionnaire on students' mental models on QP from literature was adopted. A principle component analysis of the survey data led to two independent dimensions describing the participants' mental models in QP, namely Fidelity of Gestalt and Functional Fidelity. Based on these results, we discuss a theoretical framework of mental models in QP against previous empirical studies from quantum physics education and derive implication for physics teacher education on QP.

1 Theoretical background

Learning QP is inherently difficult because it is unimaginative, counterintuitive and fundamentally different from what learners know from their everyday life and classical physics. After learning classical physics concepts, a transition to quantum thinking is challenging for many students [1, 2]. Thus, the ability to think in and with models becomes of particular importance for learning QP. However, compared to the extensive repository of physics education research on student thinking in QP [3], we still lack a theoretical description of the learners' mental models and their development processes in QP grounded on empirical findings. The transition from classical physics to quantum thinking is challenging for many students because they are numerously stuck to their realist views [5] and classic-mechanistic mental models [6]. As a result, learners often fail to develop a detailed understanding of models in QP and have difficulties in differentiating between a model and the reality described by this model [7]. Ubben and Heusler [8] investigated this shift from concreteness to abstractness in their study on learners' mental models of the atomic hull. From their questionnaire data, they extracted two independent dimensions, namely gestalt and functionality, using factor analysis describing the participants' mental models. This approach led to four archetypes characterizing possible mental modelling types in the atomic hull context depending on the extent to which the Fidelity of Gestalt and Functional Fidelity were anchored in the participants' mental models.

2 Research question and methods

Consequently, our study's main objective is to investigate if the theoretical framework to describe learners' mental models in the atomic hull context presented in ref. [8] may be generalized to different aspects of QP, e.g. indeterminism. Hence, in our contribution we report on a questionnaire study which we conducted in order to clarify the following research question: *Does the two-factorial model including the independent dimensions 'gestalt' and 'functionality' also apply to the description of students' mental models of different QP concepts beyond the atomic hull context?*

Our study was conducted with N = 280 students in total. Before our study, all of the students had participated in a first QP course. In our study, we used items from the established questionnaire on students' mental models on QP published by Müller and Wiesner [9]. Here, the students were asked to rate statements on determinism/indeterminism (sample item: *"No one can tell with certainty if a photon is transmitted or reflected at a beam splitter cube."*) and quantum objects' properties (sample item: *"In quantum physics it is possible that a quantum object does not possess classically well-defined properties, such as position."*) on a five-point Likert-scale (1 = strongly disagree to 5 = strongly agree). We conducted a correlation analysis to analyze our data, followed by a principal component analysis (PCA) to uncover the underlying structure. In order to identify the matrix of rotation, we used varimax rotation after checking the necessary prerequisites (KMO, Bartlett's Test). Cronbach's α is reported as a measure of factor reliability, and in addition we examine convergent and divergent validity. The former by calculating the average variance extracted (AVE) for each factor, the latter using the Fornell-Larcker criterion. In our oral presentation, we will in detail describe the questionnaire items and the data analysis.

3 Results

The analyzed dataset was appropriate for PCA considering the Kaiser-Meyer-Olkin-criterion since the KMO value is 0.71 and Bartlett's Test of Sphericity shows that the correlation matrix significantly differs from the identity matrix ($\chi^2(45) = 198.86$, $p < 0.001$). Considering the criteria eigenvalue, explained variance for every factor larger than 10% and scree plot bend, the PCA led to a two-factor solution (cf. figure 1). These two factors account for 44.4% of the total variance. In terms of content, the two factors reflect the Fidelity of Gestalt and the Functional Fidelity as two independent (correlation between factors ≪ 0.1) dimensions of learners' mental models in QP in accordance with those presented in ref. [8] for the atomic hull context. In our oral presentation, we will also provide insights into empirical results from psychology and neurology that strengthen the results of our questionnaire study in the quantum physics context.

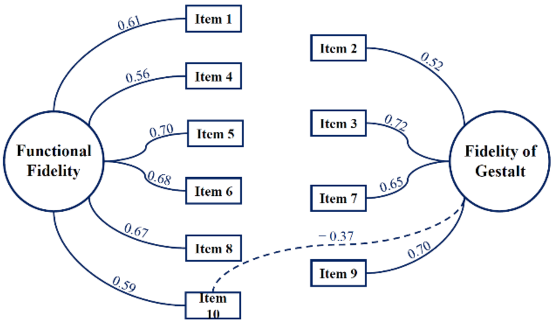

Fig. 1. The two extracted factors as well as the factor loadings $|\lambda| \geq 0.3$ of the respective items. In our oral presentation, we will provide sample items and discuss the two factors and their meanings in detail.

4 Discussion and conclusion

We conducted a questionnaire study into mental models in QP. The results indicate that Fidelity of Gestalt and Functional Fidelity form independent dimensions of the participants' mental models in QP. This result leads to four archetypes characterizing possible mental modelling types and thus to a theoretical framework to describe learners' understanding of mental models in QP which is in accordance with a previously published contribution by Ubben and Heusler [8] concerning mental models of the atomic hull. In our presentation, we describe this framework in detail, discuss our study's limitations as well as implications for physics teacher education on QP, and present research plans to validate the theoretical framework in subsequent studies.

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