Physics student understanding of quantum mechanics: a Rasch analysis

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Abstract. In this paper, we report an empirical study about undergraduate physics student understanding of quantum mechanics (QM). To this aim, we developed a multiple-choice questionnaire about wave function properties, Heisenberg's uncertainty principle and measurement in QM, atomic description of matter, which we submitted to 244 university physics students under three different instruction conditions: (i) no course, (ii) introductory course, (iii) introductory plus upper-level course. Rasch analysis was used to analyze data. Findings provided evidence that physics students, who attended the introductory and the upper-level courses, mostly obtain an informed understanding of the targeted topics. We discuss implications of our findings in light of existing research literature in physics education about QM.

1 Introduction and aims

Several studies in physics education literature suggest that students' difficulties, when first dealing with Quantum Mechanics (QM) at an introductory level, concern re-interpretation of classical physics concepts in the QM theory [1]. Typical incorrect reasoning concerns the electrons motion, the wave-particle duality, and the uncertainty principle [2]. At upper-level, students have difficulties with the concept of wave function, and the formalism of quantum mechanics [3]. However, previous studies do not provide a coherent description of the conceptual path, followed by students, when they progress in their university QM courses. This study addresses this issue through the specific research question: *How do undergraduate physics students develop their understanding of QM when exposed to different teaching conditions, from introductory to upper-level university course?*

2. Methods

2.1. Instrument

We first designed a draft questionnaire with 25 open items starting from existing instruments [4]. Topics addressed were: wave function properties, Heisenberg's uncertainty principle and measurement in QM, atomic description of matter. We piloted this version with about 30 third-year physics undergraduate students and 50 experienced physics teachers. We finally selected ten items and designed four answer choices for each item based on collected data. Answer choices were scored as: "incorrect" (1pt), "partial" (2pt), "best" (3p). Total maximum score of the questionnaire was 30.

2.2. Instructional context

This study was carried out within the context of the 3-year bachelor's degree in physics of a large university in southern Italy, where QM is taught in an introductory course (QM1) and in an upper-level course (QM2). The two courses strongly differ for the teaching focus and for the formalism used during instruction.

2.3.Sample

We involved 244 students attending the bachelor's degree in physics. Students were divided into three groups: G1 (first-year undergraduates) who had not yet received any sort of formal instruction in QM at the university level; G2 (second-year undergraduates) who had previously attended QM1; G3 (third-year undergraduates) who had attended both QM1 and QM2.

2.4. Data Analysis

Analysis was carried out through Rasch analysis [5] adopting a partial credit model. To investigate instrument functioning, we explored items' misfit and summary statistics. Point-measure correlation, item separation and person separation reliability were also calculated. To explore students' ability distribution across the questionnaire's items and to inspect differences across groups, we investigated the Wright map of our data.

3. Results

Average raw score of the questionnaire was 19.4 ± 0.5 (st. err.). Concerning instrument functioning, we found no misfitting items, which means that the Rasch model well describes our data. Item reliability is 7.39, which ensures that the sample was large enough to consider the item difficulty hierarchy valid. Person separation is 1.70, while person reliability is 0.74, which are rather satisfactory values. Most difficult items targeted wave function, while easiest ones concerned atomic description of matter. Average students' ability was 0.51 logit, which means that the questionnaire's items had a suitable difficulty for the sample. Concerning differences across groups, we found that G3 students performed significantly better than G1 (average ability: 1.06 vs. -0.17 logits), while differences with G2 students are not statistically significant (average ability: 1.06 vs. 0.73 logits).

2.4 Discussion and conclusions

Our results show that most freshman physics students at the end of secondary school hold naïve ideas about the atomic structure and wave function. Afterwards, the progress of students enrolled in the bachelor's degree in physics is nonlinear, with a significant improvement in the performances after attending the QM1 course and a more gradual refinement between the QM1 and QM2 course. Due to a longer exposure to key concepts of QM, G3 scored better than G2, but did not outperform it. Such result may be due to a different focus in the teaching of QM1 and QM2, the latter being more devoted to technical aspects, and on solving Schroedinger's equation, rather than conceptualization, discussion and interpretation of the theory.

References

[1] Singh C. & Marshman E. (2015) Review of student difficulties in upper-level quantum mechanics. Physical Review Special Topics - Physics Education Research, 11, 020117.

[2] Johnston I. D., Crawford K., and Fletcher P. R. (1998) Student difficulties in learning quantum mechanics. International Journal of Science Education, 20, 427-446.

[3] Singh C. (2008) Student understanding of quantum mechanics at the beginning of graduate instruction. American Journal of Physics, 76, 277-292.

[4] Sadaghiani R. and Pollock S. J. (2015) Quantum mechanics concept assessment: Development and validation study. Physics Review Special Topics - Physics Education Research, 11, 010110.

[5] Bond T. G. & Fox C. M. (2007) Applying the Rasch model: Fundamental measurement in the human sciences (2nd ed). New York: Psychology Press