New Teaching of Quantum Mechanics in High School

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Abstract. The currently adopted high-school curriculum of modern physics is often extremely short including a few initial steps towards quantum theory. The wave-particle duality is mentioned, but often without the meaning of wavity of particles. The contrast between the classic and quantum theories often misses any in-depth discussion. Our new curriculum adopts the paradigm of discipline-culture in representing physical knowledge. Within this paradigm, a physical theory is structured around a nucleus-body-periphery which emphasizes the principles (nucleus), their application (body) and alternatives (periphery). An experimental curriculum was developed and applied. The first results show a positive impact on students' conceptual knowledge.

1 Introduction

Quantum Theory (QT) is one of the most important developments in modern physics. However, in many countries the physics curriculum of high schools includes only a few fragments from the historical dawn of the theory such as the photo-electric effect, Bohr model of the Hydrogen atom, and radioactivity. Commonly, assessment is reduced to using a few formulas to solve simple quantitative problems. Teaching often misses the conceptual contrast between classical and quantum theories as essentially different world views. Students miss the holistic picture and structural hierarchical account of the new fundamental theory. Some researchers tried to give semi qualitative understanding of QT using a classical analogy of a string [1] while others [2] used path integral, but the lack of the whole picture still exists. School educators often explain this due to the conceptual difficulty of QT, lack of mathematical tools and allocated time. This is in contrast to introductory instruction at the university [3]. School requires a very different approach in seeking representative conceptual understanding of QT. Therefore, our study is innovative and fills the lacuna in research on teaching strategies of quantum physics with respect to wave function, quantum states and other concepts [4]. Simultaneously we tried avoiding oversimplification and distortion of QT [5]. In this study, we have developed an alternative curriculum of QT in the discipline-culture (DC) format [6] and experimentally applied it. We will present preliminary results of our experiment.

2 The curriculum

The DC splits a theory among three knowledge areas: nucleus, body and periphery. The nucleus contains core principles, the body — applications of the nucleus, and the periphery — the elements in contradiction with the nucleus. For QT, the nucleus includes particle-wave duality with regard to matter and light, the concept of states and their superposition, the probabilistic meaning of wavity and the status of measurement. The body knowledge includes illustrative experiments. The periphery includes alternatives – classical understanding and early interpretations of the QT. Experiments like the two-slit interference and the Mach-Zander interferometer illustrate the principles. Experiments are explained by the principles of state superposition, probability meaning of the wave function, and role of measurement. Competitive explanations were provided. The whole curriculum is structured accordingly.

3 Method

The developed experimental curriculum was taught in 12th grade class within the available extent of 32 hours. The group included 11 AP students of physics. Lessons were audio recorded for further analysis. Pre- and post- questionnaires were developed and applied. Some students were randomly selected for semi-structural interviews. These data were analyzed qualitatively.

There were two control groups. The first control group included students of 12th grade class who studied the regular curriculum of modern physics. The second group included undergraduate students of three universities who volunteered to participate after an introductory course in quantum mechanics. The students of the first control group completed both questionnaires, which did not address the specific contents taught to the experimental group.

4 Findings

The answers to pre-questionnaire showed that students had difficulties in understanding the pertinent material. The regular curriculum does not clearly identify such knowledge elements as principles, laws, and their applications. The post-questionnaire indicated better understanding. The experimental group showed reasonable understanding of the principles learned and succeeded in explaining situations in accordance. In some cases, the experimental group performed better than the undergraduate students who tended to describe the phenomena of matter wavity rather than explain it. High school students of the control group were confused regarding principles of QT.

To emphasize the principles of QT, we asked for the principles of classical mechanics. In this regard, we found a great confusion in both control groups. Apparently, they never considered this aspect of knowledge. Many pointed to Newton's laws but none mentioned classical state, space-time determinism and trajectory motion.

5 Discussing and Conclusion

Our results indicate that deductive teaching of quantum physics in high school as a theory possessing nucleus-body-periphery is feasible and beneficial for students' conceptual knowledge. Comparison with alternative conceptions (periphery) helped to elucidate unique aspects of the QT-principles while concrete experiments (body) used as demonstration of these principles, helped to provide concrete physical meaning to the stated principles. DC based teaching allows students to appreciate the nature of quantum theory holistically, in contrast with the university students. This is despite the very limited scope of the picture and study. The comparison to the students of regular curriculum can hardly be done because of deficient teaching of quantum theory. The comparison with university freshmen makes our success especially indicative.

References

[1] J. Petri, & H. Niedderer, A learning pathway in high-school level atomic physics, *Int. J. Scie. Educ.* **20** (1998) 1075–1088.

[2] M. Malgieri, P. Onorato, & A. De Ambrosis, Teaching quantum physics by the sum over paths approach and GeoGebra simulations. *Eur. J. Phys.* **35** (2014) 1-21.

[3] R. A. Serway, C. J. Moses, & C. A. Moyer, *Modern Physics*. Thomson Brooks/Cole, USA, 2005.

[4] K. Krijtenburg-Lewerissa, H. J. Pol, A. Brinkman, & W. R. van Joolingen, Insights into teaching quantum mechanics in secondary and lower undergraduate education. *Phys. Rev. Phys. Educ. Res.* **13** (2017).

[5] O. Levrini & P. Fantini, Encountering Productive Forms of Complexity in Learning Modern Physics, *Scie. & Educ.* **22** (2013) 1895–1910.

[6] M. Tseitlin & I. Galili, Teaching physics in looking for its self: from physics as a discipline to physics as a discipline –culture, *Scie. & Educ.* **14** (2005) 235-261.