Teaching particle-wave duality and tunneling in Dutch secondary schools

Ed van den Berg, Jeroen Grijsen, Aernout van Rossum, Henk Pol, Jan van der Veen
University of Twente, Drienerlolaan 5, 7522 NB Enschede, Netherlands

Abstract: A lessons series on quantum physics was taught to over 100 grade 12 students in 5 different secondary schools. Amongst others the series contained special demonstration experiments for particle-wave duality and tunneling. Preconceptions on particles and waves were assessed in a pretest. Student results were measured through a posttest and interviews. Some lessons were videotaped and directly observed by an outside observer. The demonstration experiments were single photon double slit interference and tunneling with microwaves. In the presentation we will focus on what students learned and what they did not learn about particle-wave duality and tunneling.

In the Netherlands quantum physics was made compulsory for all students who are taking physics in the pre-university stream and has been included in the national final examination since 2016. This concerns about 10% of the total age cohort of all 17/18-year olds, an annual total of about 20.000 students nationally. A team of teachers supported by the University of Twente developed supplementary materials including demonstrations on wave-particle duality (single photon double slit interference) and tunneling (microwaves) to support concept development, taking into account well known learning difficulties in quantum physics [1, 2]. Evaluation data were collected through lesson observations, midterm and post interviews and a pre-posttest with over 100 students at 5 different schools.

Lesson observations: One of the problems with duality is that many students insufficiently realize the conflict and surprise that we physicists think they should experience. Their background in physical optics is too limited and they are used to physics being incomprehensible and counterintuitive anyway. Wave and particle? Photons or electrons interfering with themselves in a double slit experiment? O well, why not. Of course, one could react by "nice that 21st century students are not surprised anymore by quantum theory", but we think that they insufficiently realize the meanings of wave, particle, probability distribution, and other classical and quantum concepts [1, 2]. When asked to contrast particles and waves, most students mention properties such as mass and charge for particles and wavelength for waves. However, few mention spread out in space (wave) versus well-defined location (particle). Some mention that a wave involves many particles oscillating. So we redesigned the duality lesson to articulate first the classical meaning of waves and particles and then conducted a series of double slit experiments to build up to a final surprise. We tried out this double slit lesson in other classes. Results of this are expected at by end of March.

Midterm Interviews: Generally, most students were able to reproduce the basic facts and interpretations about duality and tunneling which were asked in interviews using the PhET applets during the interview. Even a pair of students who did not remember the word tunneling ("*we have no idea Sir*"), could remember the basic facts and interpretations when they saw the applet. They correctly interpreted the amplitude of the wave function and predicted correctly what would happen to the probability of reflection and transmission if the barrier height or thickness would be increased or decreased. Of course deeper problems with quantum representations are likely to still be present [3].

Post interviews and a posttest will take place in March and data will be analyzed in April. Translated lesson materials and a research paper will be available at the GIREP presentation.

References

[1] Muller, R., Wiesner, H. (2002). Teaching quantum mechanics on an introductory level. *American Journal of Physics*, 70(3), p200-209. DOI: 10.1119/1.1435346

[2] Krijtenburg-Lewerissa, K., Pol, H., Brinkman, A., Joolingen, W. Van (2017). Insights into teaching quantum mechanics in secondary and lower undergraduate education. *Phys. Rev. ST Phys. Educ. Res*. 13, 010109 (2017). DOI: 10.1103/PhysRevPhysEducRes.13.010109

[3] McKagan, S.B., Perkins, K.K., Wieman, C. E. (2008). Deeper look at student learning of quantum mechanics: The case of tunneling. Physical Review Special Topics. 10.1103/PhysRevSTPER.4.020103