Quantum Physics for all – Using ICT to experiment and simulate quantum principles

Vassilis Dimopoulos , George Kalkanis
Science, Technology and Environment Laboratory, Pedagogical Department of P.E., University of Athens, Greece
bdimo@primedu.uoa.gr

Abstract

The effort to enrich a university course of non-physics major direction, with principles of quantum mechanics is mainly not allowed because it demands strong competences in physics and mathematics. This obstacle can be surpassed by the use of ICT applications and hands-on activities. This academic year a research – concerning the efficiency of the comprehension of quantum principles by students with limited math / physics background– was conducted to four classes of the Pedagogical Department of the University of Athens. In order to support the intervention, educational material was developed including the subjects: mechanic waves, duality of light with reference to duality of electrons, linear spectra, phenomena of probabilistic microcosm and quantum mechanic model of Hydrogen (including 2D and 3D models of the atom representing the radial probability distributions of an electron for the 1S, 2S and 2P states in hydrogen) The use of simulation and dynamic visualization, in combination with the developed material, served as an instructional tool to teach contemporary physics issues to non-major Physics Department students.

Introduction

The effort to teach students of secondary education or these of university courses of non-physics major direction, principles of quantum mechanics is mainly not allowed because it demands strong competences in physics and mathematics. This obstacle seems able to be surpassed by producing *curricular models* [1] from *scientific* and *historical models* and by using simulations / visualizations in order to model the microscopic world with coherence to the theory [2], accompanying the intervention with special *supporting material*.

1 The Software

1.1 The characteristics

In order to support an intervention concerning modern physics, educational material was developed, with the following characteristics:
a) methodology based on the educational method [3]. The consisting steps of the method, in both options, may be described as:

Scientific method	*Educational method*
trigger in research	trigger student's interest
making hypothesis	questioning the problem
experimentation	work in the lab or/and in situ
developing theory	conclusions
testing of theory	problem transfer, generalization

b) scientific and historical models transformed to curricular / educational models
c) simulations / visualizations of probabilistic microkosmos and quantum mechanic model of Hydrogen, based on methods of the stochastic analysis and Monte Carlo techniques [4],
d) hands on experiments in order to study phenomena concerning the wave nature of light (diffraction, interference) or different spectra,
e) web-based environment.

1.2 The contents

The software includes six units:
1. *mechanic waves* (examining the characteristics of a wave, longitudinal and transverse wave, wave interference, stationary waves),
2. *duality of light* (including experiments with laser in order to show interference –Figure 1-, diffraction and a simulation program for the photoelectric effect) and reference to historical experiments such as the two slits experiment of Claus Jönsson in 1961 [5], [6],

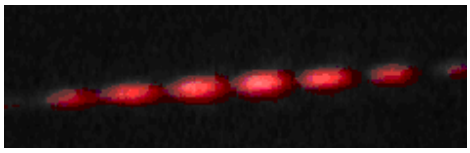

Figure 1. Interference pattern

3. *spectrum* [7] (including experiments with spectroscope),
4. *early models of atom* (including the Thomson's, the Rutherford's model and the Bohr's atom of hydrogen),
5. *the quantum model for the atom of hydrogen* (including 2D and 3D models of the atom which have been developed in 3d studio max, representing the radial probability distributions of an electron for the 1S, 2S and 2P –figure 2- states in hydrogen),

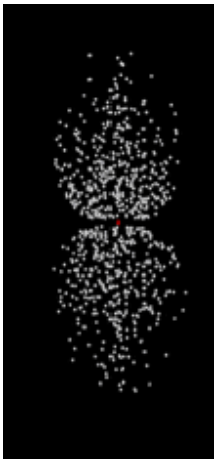

Figure 2. Electronic cloud for the n=2, l=1, m=0 state of the atom of hydrogen

6. *electric current*, in order to show an application of quantum mechanics to phenomena that can be explained by both a classical and quantum mechanic model (concerned to be the latest scientific model).

2 The Research

The software was implemented in four classes of 120 students of the Pedagogical Department of the University of Athens. The students had limited mathematics and science background and were on the third year of their studies, taking the obligatory physics lab course. Two of the classes underwent the intervention, while the others were the control group. At the beginning of every unit a questionnaire (pre-test) was distributed to the students, while another one (post-test) was given to them a week after the intervention and a final one at the end of the second semester.

Conclusions

The pre-test questionnaires elicited the pre-conceptions and mental models of the students concerning major principles of quantum mechanics and models of the atom of hydrogen, similar with other researches [8], [9], [10]: students are not used to tolerating with different models and confuse concepts of these different models (i.e. Bohr's model and orbital model), while the dominant model of the atom of hydrogen is Bohr's model. The use of simulation and dynamic visualization (in order to surpass the obstacle of the limited math / physics background), in combination with the developed material, contributed to an important degree to the understanding of quantum mechanics principles (duality of light, non-locality, Heisenberg's principle) and helped students to distinguish among different scientific and historical models.

References

[1] GILBERT J., JUSTI R., AKSELA M. Visualization: A metacognitive competence in the learning of science. 2003, 4th ESERA Conference, Noordwijkerhout, The Netherlands

[2] MICHELINI M., SANTI L., STEFANEL A., MENEGHIN G., A resource environment to introduce quantum physics in secondary school, Proceedings of the 7th Workshop on Multimedia in Physics Teaching and Learning of the European Physical Society, 2002

[3] DIMOPOULOS V., KALKANIS G., An introduction of microcosmos quantum model to students of limited mathematics and science background supported by computer simulations / visualizations, 4th ESERA Conference, Noordwijkerhout, The Netherlands, 2003

[4] KALKANIS G., HADZIDAKI P., STAVROU D., An Instructional Model for a Radical Conceptual ChangeTowards Quantum Mechanics Concepts, *Science Education,* 2002

[5] Editorial, The double-slit experiment, *Physics World*, 2002

[6] FISCHLER H. AND LICHTFELDT M., Modern physics and students' conceptions, *INT. J. SCI. EDU*,14 (2),1992, pp 181-190

[7] ZOLLMAN D., REBELLO N., HOGG K., Quantum mechanics for everyone: Hands-on activities integrated with technology, *Am. J. Phys. 70* (3), 2002

[8] OLSEN R., A Study of Norwegian Upper Secondary Physics Specialists' Conception of Atomic Models and the Wave Particle Duality, Proceedings of the Third ESERA conference *Science Education Research in the Knowledge based society*, Thessaloniki, Greece, 2001

[9] PETRI AND NIEDDERER, A learning pathway in high-school level quantum atomic physics, *International Journal of Science Education*, Vol. 20 No. 9, 1999

[10] PETRI AND NIEDDERER, Atomic Physics in Upper Secondary School: Layers of Conceptions in Individual Cognitive Structure. Proceedings of the Third ESERA conference *Science Education Research in the Knowledge based society*, Thessaloniki, Greece, 2001