Science Instruction with the use of Information Communication Technologies – – Suggestions and Applications of Quantum Approaches

PhD student: Vassilis Dimopoulos, Supervisor: prof. George Kalkanis

Science, Technology and Environment Laboratory, Pedagogical Department P.E., University of Athens, Greece

ABSTRACT

An effort to enrich a university course of non-physics majors, with principles of quantum mechanics is mainly not widely supported because it demands strong competences in physics and mathematics. This obstacle can be surpassed by the use of ICT applications and hands-on activities. A research was conducted the academic year 2003 - 2004 to 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, attending an obligatory physics lab course. Two of the classes underwent the intervention, while the others were used as the control groups. In order to support the intervention, educational material was developed including the subjects: mechanical waves, duality of light –with reference to duality of electrons–, line spectra, atomic models for the atom 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 physics majors.

INTRODUCTION

Although quantum mechanics has changed forever our picture of the world by introducing indeterminism, probabilities and nonlocality into the foundations of physics (Muller et al, 2002), the science education content is, in general, organized in a scheme that mainly includes the knowledge of the 19th century, leaving limited space for the knowledge of the 20th century, the so-called “modern” physics (Kalkanis, 2001). Moreover, although the knowledge of the 20th century was followed by the development of devices that can be appreciated only through the principles of quantum mechanics, non-physics majors students not only lack information on the last scientific models but what is more they cannot understand the way modern technological civilization works.

THEORETICAL FRAMEWORK – AIMS

The effort to enrich a curriculum of secondary education or a university course for non-physics majors, with 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 the use of simulations / visualizations in order to model the microscopic world with coherence to the theory (Michelini et. al., 2002). Moreover simplified versions of scientific and historical models should be produced as curricular models (Gilbert et al, 2003).

Our research aims to surpass the epistemological and cognitive obstacles, which arise at the process of learning concepts relevant with quantum physics. One basic aim of the research is the reconstruction of the curriculum of a science course of a pedagogical department, the design of an educational approach and the development of educational material on the direction of quantum mechanics.

REVIEWED LITERATURE

The so far reviewed literature brought out researches that took place in different countries in order to estimate the mental models of students of upper high school (Olsen, 2002; Ireson, 2000), of students of Physics Departments (Muller, 1999; Johnston et. al., 1998) or of students of non-major physics Departments (Zollman, 1998), concerning quantum phenomena (duality of light / electrons, non locality…) and the atom of hydrogen, while in some cases the research is followed by an intervention based on educational material which includes simulations / visualizations, animations, applets. Concerning the atom of hydrogen, different educational models are used in education, such as energy levels (Zollman et al, 2002), orbitals (Robblee et al, 1999), the "electronium" model (Budde et al, 2002) and the parallel introduction of Bohr's model and orbitals (Kalkanis et. al., 2003).

RESEARCH QUESTIONS

The main research question is whether an educational / curricular quantum model may enhance the comprehension of quantum physics by students with limited mathematics and physics background. According to Muller and Wiesner (2002), although the Bohr's model is not compatible with the quantum mechanical conception of the atom, it can function as an intermediate step. Possibly the lack of a comprehensive visualization of the quantum mechanical model, forces students to stick to Bohr's model, so the goal of our instruction should not be to erase the Bohr model in the students' minds, but to convey the conscious use of physical models and help them have insight into the models' limitations. Hence, another question is whether the parallel introduction of scientific models –probability quantum model and Bohr's model– for the description of the atom of hydrogen, can help students to distinguish among concepts of these models (Kalkanis et al, 2003; Hadzidaki et al 2000). Finally, another question is whether a simulation program, which visualizes the probability quantum model representing the radial probability distributions of the atom of hydrogen, can influence students' preference of the one (the probability model) or the other model (the Bohr's model) when describing the atom of hydrogen.

THE SOFTWARE – DESIGN OF THE RESEARCH – METHODOLOGY

In order to support the intervention, educational material was developed, two years ago, with the subjects: duality of light (including experiments with laser in order to show interference and a simulation program for the photoelectric effect), line spectra, the Heisenberg's principle and phenomena of probabilistic microcosm and quantum mechanic model of Hydrogen. The previous year a pre-evaluation of the educational material took place (Dimopoulos et al, 2003) and for the academic year 2003 - 2004 new subjects and elements have been added to the educational material concerning mechanical waves, diffraction and reference to historical experiments such as the two slits experiment of Claus Jönsson in 1961 (Editorial of Physics World, 2002; Fischler et al, 1992) while 2D and 3D models of the atom have been developed, in 3d studio max, representing the radial probability distributions of an electron for the 1S, 2S and 2P states in hydrogen.

The developed educational material has the following characteristics: a) methodology based on the educational method, 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, d) hands on experiments in order to study phenomena concerning the wave nature of light (diffraction, interference) or different spectra, e) web-based environment. The software includes six units: 1. mechanical waves, 2. duality of light, 3. spectrum, 4. early models of atom, 5. the quantum –probability– model for the atom of hydrogen, 6. electric current.

DESCRIPTION OF THE INTERVENTION

The educational material was under evaluation from the beginning of the winter semester of the academic year 2003-2004 until the end of the summer semester on four classes of 121 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 used as the control group only for the units of “The atom of hydrogen” and the “Electric current”. The following table (table I) shows a schedule of the intervention.

Table I

	Unit	*The intervention*	*Class organization*
1^{st} week	mechanical waves	Characteristics of a wave (part A)	*4 classes: 121 students*
2^{nd} week		Longitudinal and transverse wave (part B), Wave phenomena (part C)	
3^{rd} week		stationary waves (part D)	
4^{th} week)	duality of light / electrons	Diffraction (Part A), interference –figure 1– (Part B) with reference to historical experiments such as the two slits experiment of Claus Jönsson in 1961	*All groups undertook the same intervention*
5^{th} week		photoelectric effect (part C)	
6^{th} week	Spectrum	Line spectra (including experiments with spectroscope)	
7^{th} week	Early models of atom	Brown’s motion (Part A) the Rutherford’s model (part B) and the Bohr’s atom of hydrogen (part C)	
8^{th} week	The quantum –probability– model for the atom of hydrogen	The atom of Hydrogen	*2 classes: 60 students (experimental group) 2 classes: 61 students (control group) Both the groups undertook the same subject. In order to introduce the probability model to students of the experimental group simulation program of 2D and 3D models –figure 2- of the atom were used. Only static icons were used for the description of atom, at the control group*
9^{th} week	Electric current	Electric current	
3 months later		Final Post test of all the units	
* A pre test and a post test (a week after the instruction of each unit) was distributed to the students			

Schedule of the intervention

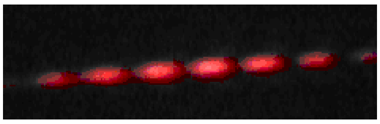

Figure 1. *Interference pattern*

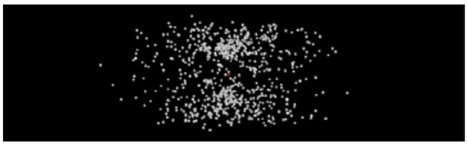

Figure 2. *Probability model for the n=2, l=1, m=1*

THE QUESTIONNAIRES – ANALYSIS OF THE RESPONSES

All the questionnaires (pre, post and final post test) included open ended and multiple choices questions. Some typical questions are:

"The following picture is the diffraction pattern of electrons and shows the wave-nature of electrons. Can you argument on the particle nature of light?", "Suppose that on a paper you make two holes with diameters close to the wavelength of a laser beam … What to you expect to see on the screen if you light the slit with the laser beam? (Draw and describe)", "Discuss on the nature of light", "Discuss on the nature of electrons", "Design and describe a model for the atom of hydrogen (nucleus and one electron)."…

In order to analyze the responses we have followed two approaches a qualitative – phenomenographic analysis (Johnston et al 1998; Unal et al, 2000)– and a quantitative one – using the t-test. For the phenomenographic analysis we followed three principles (Unal et al, 2000): a) categories were extracted from the student responses; so we didn't have pre-assigned categories, b) categories were not mutually exclusive or inclusive, but distinguishable, c) responses were explicit to be categorized.

Comments on the Diffraction / Interference

The answers of the students at the relevant pre test shows that they were not aware on what happens at the diffraction and interference of light / electrons and at the photoelectric effect. After the intervention students could answer in a satisfactory way on questions concerning diffraction and interference of light / electrons. For the case of the photoelectric effect students on a question concerning the intensity of light at first believe that when the intensity of light arise then not only the number of the emitted electrons arise but also their kinetic energy arises too, while few of them could answer correctly that the kinetic energy of the emitted electrons is proportional to the frequency of light. The intervention helped students to understand the effect of these factors.

Comments on the duality of light / electrons

For the nature of light and electrons we have included some questions from a questionnaire of Olsen for students of upper secondary schools in Norway (Olsen, 2001). The analysis of the student's responses in the pre test showed that students do not conceive of light and electrons as having a similar nature. Electrons seem to be conceptualized as particles while light seems to be perceived as having a dual nature. Most of the students who argued that light have a dual nature were not able to give answers that explicitly addressed the nature of this dualism and most of the students who argued that electrons have a particle nature were not able to give answers that explicitly addressed the particle nature of them. At the post and final post test students conceive of light and electrons as having a similar nature. In the Post / Final Post Test reference to phenomena (e.g. interference or diffraction, photoelectric effect) is commonly made to explain the dual nature of light while in order to explain the dual nature of electrons reference to phenomena (e.g. interference or diffraction) and a defining property (e.g. mass or charge) is commonly made. Some of them in order to argue for the duality of light / electron refer to the complementarity principle. Even after the intervention students were not able to find arguments (rather than mass or charge) on the particle nature of electrons. That is because the unit *duality of light / electrons* focuses on the wave nature of electrons. In the following diagram (figure 3) appears the mean value of the total scores for the answers of the questions relevant to the nature of light / electrons for the three tests.

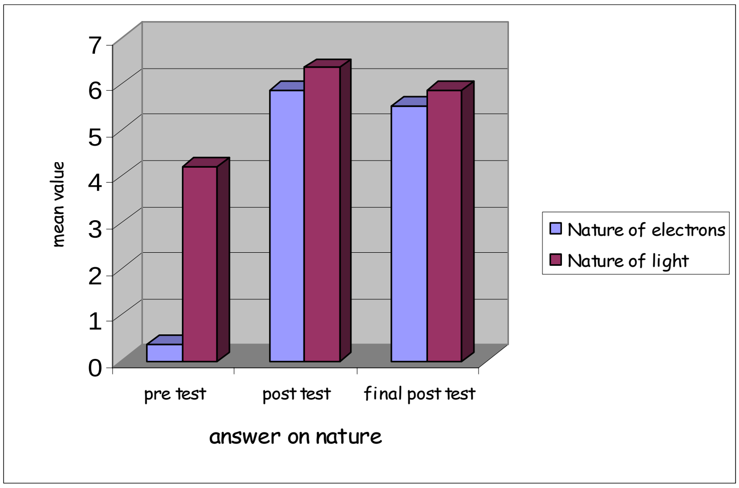

Figure 3. Diagram of the mean values for question concerning the nature of light and electrons

Comments on the atomic model

In the pre test and the post test students were asked to describe a model of the atom of hydrogen –a question, also, used in other researches (*Unal et. al., 2000*; *Petri et.al., 1998*). In the final post test students had to describe the atom of hydrogen using both the Bohr's model and the probability quantum model. All the answers were categorised and the extracted categories are presented in the following table (table II). The letters "b" and "q" define whether the answers are closer to the Bohr's model or to the probability quantum model and the numbers define the different categories derived from the answers.

Table II

1b	all the conditions from Bohr’s theory
2b - 4b	missing condition(s) from Bohr’s theory
5b	electron moves around the nucleus
1q	probability model, quantum numbers / frequency of finding the electron in Bohr’s radius is higher / reference to the Heisenberg’s principle
2q	electrons move around the nucleus without following a specific orbit. Visualizing the possible positions probability model is shaped
3q	Schrödinger's equation is used in order to calculate the possibility of finding an electron in a specific area / it is impossible to know the accurate position of an electron in a specific position
4q	electron can be found in a specific position
5q	the possible position of the electron is determined by three quantum numbers
7b or 6q	Thomson’s model
6b	irrelevant response
NA	No answer

Extracted categories for the description of the model for the atom of hydrogen (both post and final post test)

The percentage of the students, who described the atom according to each category for the case of the post test, appears in the following table (table III).

Table III

	Experimental group (%)	Control group (%)
1b	3	0
5b	23	25
1q	7	2
2q	30	16
3q	2	1
4q	2	0
5q	0	0
6q / 7b	0	2
irrelevant response	12	21
NA	21	33

Percentage of students who described the atom according to each category for the case of the post test

In the final post test students were asked to describe the atom of hydrogen with both the Bohr’s and the probability model. The extracted categories were the same with table II and the answers were marked from 0 – 10. The t-test was used in order to show whether there are any statistical differences among the responses of the groups. The mean values for the answers concerning the probability model are:

	Experimental group	Control group	p
Description according to probability model	6.67 ± 2.07	5.03± 1.25	0.026

Mean value of the experimental and the control group

The mean values for the answers concerning the Bohr's model are

	Experimental group	Control group	p
Description according to Bohr's model	5.83 ±1.87	5.33± 1.35	n.s

Mean value of the experimental and the control group

The analysis of the student's responses in the pre test showed that the dominant model of the atom of hydrogen is a simple orbital model, something that is in coherence with other researches (Olsen 2001, Mashhadi 1996, Müller et al, 1999, Unal et. al 2000). The analysis of the responses showed that in the post test most students of the experimental group described the probability quantum model while the students of the control group preferred the Bohr's model something that indicates the influence of the simulation program to the students of the experimental group. In the final post test the analysis of the responses showed that students of all groups could describe as well the Bohr's and the probability model –without confusing concepts of these models–, although students of the experimental group received again a higher score –compared to that of the control group– when they described the quantum mechanic model.

CONCLUSIONS

After the intervention there has been an improvement in performance on questions that probed students understanding of issues concerning modern physics. Moreover students having used instructional software, including simulation / dynamic visualization models, concerning contemporary topics of physics were efficient to describe such models and to distinguish among different models. The total score of the correct answers both in the post and the final post test was in the same level. We note that the time difference between the two tests was 3 months and the questions included both comprehension and knowledge recall questions. Finally there is evidence that an introduction to quantum mechanics to students with limited mathematics and physics background may be achieved up to a level by the educational approach we propose.

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