Design, Description, Implementation and Assessment of a Multimedia Application with Simulations for Teaching Models of Light

Nikolaos Voudoukis

Abstract—In this study it is described the use of software and simulations at a didactical approach-teaching method about models of light to upper secondary education students and non-major science university students. Light and models of light, is a subject proving too difficult to be taught. A research - didactical intervention was conducted to secondary education students. In order to support the intervention, educational material was developed including the subjects: Propagation, Reflection, Interference – Diffraction, Refraction, Absorption, Analysis – Synthesis and Polarization of light. The multimedia application with simulations is a proposal for a teaching approach concerning models of light. It was applied during the school years 2015-2017 to one hundred forty-three (143) students of upper secondary education in Athens, Greece. We present the educational software and the assessment/evaluation of this software. Results and some general conclusions from the statistical analysis of this computer supported attempt are also cited.

Index Terms—Multimedia; Simulation; Software; Models of Light; Assessment; Evaluation; Education; Educational Technology.

I. INTRODUCTION - RATIONALE

Quantum light looks like a mysterious thing: Is it wave, particle, both, or neither? The wave-particle duality of light is very difficult to visualize and also it is challenging to find a successful model for the properties of light.

In this study we describe the use of software and simulations at a didactical approach-teaching method about models of light to secondary education students (and probably for non-major science university students). Basic purpose for this effort is to use experiments and simulations as a proof and explain tool for phenomena, properties and nature of light. The educational material of the intervention includes the subjects: Propagation, Reflection, Interference – Diffraction, Refraction, Absorption, Analysis – Synthesis and Polarization of light.

II. BACKGROUND, FRAMEWORK AND PURPOSE

The way of teaching the nature of light has no significant change the last decades. Currently, there are several attempts for software-supported instruction methods for teaching nature and properties of light.

There are some efforts for the design, development and evaluation of software concerning properties and nature of light [1]-[3].

The way that light can be approached by university undergraduate students [4] and secondary education (high school) students [5],[6] is an open subject for investigation, especially for secondary education students and non-major science university students, i.e. students without the necessary background of mathematics and physics.

Mc Kagan et. al developed The Physics Education Technology (PhET) Project which includes simulations on quantum mechanics [1]. S. B. McKagan et al, developed a curriculum on light including interactive computer simulations, lectures and homework problems [7].

The studies concerning wave-particle duality indicate the difficulty of the concept. The phenomenon of wave-particle duality challenges the classical way of thinking and understanding.

III. EDUCATIONAL AIMS

The aim of this study is to propose a new didactic approach / a model for teaching light - Scientific to Educational Models Transformation, concerning wave-particle duality of light, for secondary education students and non-major science university students. Basic purpose for this effort is to use experiments as a proof and explain tool for light phenomena, properties and nature [8].

The purpose was the study of software, simulations and hands-on experiments for a phenomenon/property (reflection, refraction etc.) of light from students and the selection (after this study) of the appropriate model of light (wave, particle, both, neither) which explain the specific phenomenon [8], [9].

Contemporary scientific theories are included to the current curriculum for secondary physics education in Greece. This is the reason for the choice of the topic.

We have created a computer - based interactive multimedia application for training in models of light. We apply the innovative teaching method using the developed software and evaluate the educational application (students answer questions) compared with the traditional lectures. The teaching material and method was assessed by properly designed questionnaires. The questionnaires included application design and operation.

Main characteristics of the proposed teaching method are: a) scientific models transformed to educational models, b) simulations / visualizations, c) hands-on experiments in order to study phenomena concerning the nature of light, d) web-based environment [10]-[13].

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N. Voudoukis is with the National Technical University of Athens, Greece. (e-mail: nvoudoukis@aspete.gr)

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IV. SOFTWARE DESCRIPTION


The developed software includes the above seven units. The software is a computer-based interactive multimedia application created in the form of HTML pages, including simulations created with 3D Studio Max and Visual Basic 6.0 + OpenGL. Moreover, the didactical approach is a combination of software (simulations, visualizations, theory presentation) and experiments in laboratory (in the classical way). It includes the five aforementioned steps of the educational model.

The intervention was performed, at secondary education students in Athens, Greece during the school years 2015-2017. The number of students participating in this study was 143, divided into six groups of 24 each (one group was of 23 students). Every group was divided in 12 teams of 2 students.

The purpose was the study of software, simulations and hands-on experiments for a phenomenon/property (reflection, refraction etc.) of light from students and the selection (after this study) of the appropriate model of light (wave, particle, both, neither) which explain the specific phenomenon [8].

Every team of two (2) students was given a computer with the software and a brochure (2-3 sheets) of instructions and questions. They navigated the software and executed the hands-on experiments following the instructions and answered the questions. At the end of the lesson, the students returned the completed brochure to the instructor-teacher who was present during the whole time.

V. THE MULTIMEDIA APPLICATION

There was a teaching strategy for developing the educational application. Multimedia and interactivity was the main point of the design with respect in teaching content (nature of light, models and properties of light). Texts, photographs, graphics, animations, videos, multiple choice-tests, simulations, instructions for hands-on experiments application carefully chosen are used in this software.

The content of the course has been divided into seven units. In every unit there are three (3) parts: wave model of light, particle model of light and the main subject of the unit (e.g. Reflection of light). The two parts, wave model of light and particle model of light are the same in every unit. This is for the purpose of the possibility of independent teaching of each subject-unit.

The basic content that student must learn is organized with a proper way in these seven units.

Each of the units (blocks-sub subjects) of the course includes five steps to organize methodically the instruction and learning procedures 1. Trigger of interest 2. Hypothesis expression 3. Experiments 4. Conclusions and proposals - recording 5. Generalisation - feedback – control.

Students are not required to have experience with computers and the application is user-friendly, with every block being accessible at all times.

Through application has been sought continual interactivity that enables learning to be more flexible and better adapted to the student’s personal requirements. Students are able to interact easily with the software through links connecting the various elements. These links-icons are used in a consistent manner leading to users’ quick familiarisation with the application interface.

VI. DESCRIPTION OF THE UNITS

The software includes the following seven (7) subjects-units: Propagation, Reflection, Interference – Diffraction, Refraction, Absorption, Analysis – Synthesis and Polarization of light.

The following pictures are examples of software screens (simulations, visualizations, text, buttons and instructions).

Fig. 1. One of the triggers, Particles-Photons in fiber (visualization)

Fig. 2. Simulation, Reflection of light (light-particle)
Fig. 3. Simulation, diffusion of light (light-wave)

Fig. 4. Simulation Refraction of light (light-wave)

Fig. 5. Simulation, interference of light (light-wave) at a point

Fig. 6. Simulation, interference of light (light-wave) at a surface

Fig. 7. Simulation Diffraction of light (light-wave)

Fig. 8. Simulation, Refraction of light (light-wave)

Fig. 9. Simulation, Refraction of light (light-wave)

Fig. 10. Simulation, Refraction of light (light-particle)
VII. ASSESSMENT/EVALUATION OF MULTIMEDIA APPLICATION

The multimedia application described and the effect of the application’s design are analysed.

Students were very satisfied. They evaluated the software and clearly confirmed that is user-friendly, easily operated with no previous computer experience to be required.

The active learning process made students to be focused on their subject. The information needed from the students was easily accessed (successful navigation system) helping them completing the learning activities.

This software application supports the didactical approach to models of light providing a learning way that is flexible with relative adaptation to each student’s individual study rhythm [8],[9],[13].

From the questionaries’ analysis it can be seen that students consider the instructions to be clear and the software-application is intuitive, easy to use and favour the understanding of the concepts.

VIII. COMPARISON OF TEACHING METHODS - QUESTIONNAIRES OF SOFTWARE ASSESSMENT AND RESULTS

The proposed educational application, as teaching method is compared with the traditional teaching. The results of this comparison are very encouraging for the proposed application and the developed software to accompany the application. A scale of 1 to 5 was used to score the items [14].

The average grade on all questions asked significantly differs from 3, meaning that there is no parity between the two methods. Analysing the scores to see whether they are above or below 3, it can be seen that educational application used as a teaching instrument receives better scores than traditional on-site teaching in all the aspects under study.

Finally, students were requested to grade the following statement: “I believe that this teaching method would be applied again in the future for other students”. Students agree with this statement. This leads us to believe that the experience responded to students’ original expectations and that they were satisfied from the teaching method.

Number of students: 143

The rating scale is as follows [14]:

5 = strongly agree,
4 = somewhat agree,
3 = neither agree nor disagree,
2 = somewhat disagree,
1 = strongly disagree

A. Software assessment by students

<table>
<thead>
<tr>
<th>STATEMENT</th>
<th>RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>This type of instruction improved my understanding of the material.</td>
<td>94</td>
</tr>
<tr>
<td>I learned what material was most important during this type of instruction.</td>
<td>62</td>
</tr>
<tr>
<td>This type of instruction made the material easier to understand.</td>
<td>98</td>
</tr>
<tr>
<td>I enjoyed the way topics were covered by this type of instruction.</td>
<td>50</td>
</tr>
<tr>
<td>This type of instruction helped class participation and involvement.</td>
<td>60</td>
</tr>
<tr>
<td>Material was fun to learn about during this type of instruction.</td>
<td>58</td>
</tr>
<tr>
<td>I felt rushed during this method of instruction.</td>
<td>1</td>
</tr>
</tbody>
</table>

Number of students: 143
B. Questions - Comments for the software

1. When watching the computer activities, were you ever frustrated? If so, describe briefly the reason for your frustration.

YES: 37
Reason: a little in the beginning, a lot of information, many things, little time, not enough knowledge of computer-informatics, the last activities more complex, abstract concepts.

NO: 106

2. Was the computer display on the screen always easy to see (with appropriate font size, suitable colors, sharp images, etc.)? If not, which displays were problematic and how often?

YES: 124
NO: 19
Reason: in some places, a little small letters, "some have myopia."

3. Did you usually understand the computer program’s main objective? That is, what it was all about? If not, which activity was difficult to see what it was for?

YES: 134
NO: 9
Reason: sometimes a little tricky because of difficult terminology.

4. Are the concepts and terminology in the computer activities related to the material covered in the class lectures? If not, how often is this problem?

YES: 126
NO: 17
Reason: some unprecedented issues and interests.

5. Were any of the activities tedious or boring? Which ones?

YES: 21
Reason: "Those that I did not understand", some abstruse

NO: 122

6. Were any of the activities particularly interesting? Which ones?

YES: 140

Reason: themes questions for next time, or experimentation in the laboratory or at the computer, light transmission, fiber optics, reflection, refraction, interference, diffraction, analysis, composition, colors, polarization.

NO: 3

The questions 1-6 and answers, in summary, are as follows [14]:

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>YES</th>
<th>NO</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>37</td>
<td>106</td>
</tr>
<tr>
<td>2</td>
<td>124</td>
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<tr>
<td>5</td>
<td>21</td>
<td>122</td>
</tr>
<tr>
<td>6</td>
<td>140</td>
<td>3</td>
</tr>
</tbody>
</table>

7. Please add any other comments you’d like to make about the computer activities or the course in general.

C. Students’ interesting comments for the software

The comments listed below were made by the students at the end of the series of seven exercises under completion, anonymous questionnaire of assessment - evaluation of educational software.

- The activities were interesting. There was no problem with the exercises. Everything was perfectly organized and meticulous. All showed interest.
- All things were made through a very pleasant atmosphere which is created and a positive attitude for the course.
- I think that optics experiments were more interesting than the corresponding software. The content of the activities, in the theoretical part, was perfectly understandable. I quite liked the visualizations.
- These activities were particularly interesting because they were mostly using software, which helped us to better understand the various concepts. In my opinion it will be helpful all students to have the same instruction.
- I think it was all very carefully structured. They helped me immensely in understanding the concepts, the applications often did at the laboratory bench.
- I think it was very well organized all the activities of the software and should establish their use in all laboratories. All students should have access to this software.
- I think these seven exercises are especially important for our educational activity in the future.
as teachers. The only item that might make them a bit tedious is the need to complete the brochures.

- It covered the most part of the issues with which we were dealing. Were fully understood the exercises and experiments. Highlights the most key points and concepts the teacher must know.
- It greatly helps to understand the syllabus. It especially facilitates better understanding of some phenomena through experiments.
- The process that we followed was very interesting, first theory and activities in computer and then experimenting on them.
- Good and targeted effort to introduce new technologies in the educational process.
- The activities of the software were quite interesting.
- At that time, I took a tip about the wave-particle duality of light.
- Some concepts that would be difficult to explain theoretically, became easy to understand through the activities of the software.
- The activities of the software were pretty good and interesting, to attract, to "collide" with new and existing information and lead you down the path of better understanding and role models.
- The software simulations and activities were very interesting. The whole effort is worthwhile. Congratulations!
- This software could be added in the theoretical part of the course of physics
- You might need more vivid colours and larger screens.
- General visualization is very useful, especially in cases of such theoretical issues.
- Very good effort. Sufficient working concepts and understandable form through simulations.
- It was something very interesting. I will try to implement something similar and relevant to my class.
- This software helped me understand concepts which when we had last year at the theoretical level in Physics I and II seemed unreachable.

IX. COMMENTS ON RESULTS

The statistical analysis of students’ answers show that the software is suitable for teaching, easy in use, attractive without requirements for prior computer training. Students’ positive comments indicate their satisfaction from the use of the proposed learning environment.

The design of the application environment, as students believe (answers, comments) is simple, clear and intuitive to use. The navigating through the various modules was very easy and software’s control was high. These characteristics enabled students to focus all their efforts on the content of every module and enhance the learning procedure.

The potential of the software as a self-learning tool is supported by the flexibility (different learning styles, various multimedia tools). The software could be helpful for teaching not only in the classroom but also as an asynchronous teaching platform. Also the designing of the material is developed in such way that is suitable for online communication and virtual platforms (e.g. independent learning process, interaction between teachers and students) [15], [16].

Students’ preference of the teaching method with use of the software versus traditional teaching is confirmed from the assessment procedure grades (answers, comments).

The scores- results from the assessment of a mixed teaching system (experiments in laboratory and software simulations) demonstrate that students are positive with the use of the multimedia software.

X. CONCLUSIONS AND IMPLICATIONS

For a long period of time there was an oscillation of people's ideas about the nature of light between a particle model and a wave model [17], [18]. Wave-particle duality is characterized the nature of light. The visualization of this duality is a very difficult subject.

The research suggested that light is a difficult topic to teach to students without the appropriate background in mathematics and physics. The assessment of our didactical approach makes clear that it is appropriate for teaching models of light and properties of light. We are confirmed that it is appropriate for secondary education students and also we think that it will be appropriate and for non-major science university students too.

This topic is chosen for secondary students (17-years-old), although they don’t have the appropriate mathematical background, because the current physics education curriculum in Greece includes references to wave-particle duality of light (nature and properties of light) [8],[9].

A methodology in teaching is a very important matter and students need to have a methodology in their studies. The concept of light duality in physics should be taught having as basic methodology the reference of unified theory and developing-proving particle and wave theories as approximations to this (their validity is correct under certain definable conditions).

For this study we ought to say that it was carried out in a controlled environment. This is a limitation but in the same time introduces a key-parameter for avoidance of undesirable situations.

The conclusions (from the analysis of the assessment results) show the beneficial contribution of multimedia application use in teaching the nature of light (models of light and properties of light). We think that this way of teaching approach could be extended to other related subjects from physics, especially contemporary physics theories (quantum physics, theory of relativity).

Multimedia applications support new methods for flexible and quality training. This conclusion is confirmed by our design, description, implementation and assessment of a multimedia application with simulations for teaching models of light and students’ perceptions when using it.
REFERENCES


Nikolaos Voudoukis received a BSc degree in Physics from Athens National University, Greece, in 1991, a BSc in Electrical and Computer Engineering from the National Technical University of Athens, Greece, in 2012, his MSc degree in Electronics and Telecommunications from Athens National University, in 1993, and his PhD degree from Athens National University, in 2013. He has worked as telecommunication engineer in Greece, as teacher and Assistant Director at a high school and as a part-time Lecturer at the School of Pedagogical & Technological Education, Athens, Greece. Dr. Voudoukis now is with National Technical University of Athens, Greece.

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