Available online at www.sciencedirect.com
ScienceDirect
Procedia - Social and Behavioral Sciences 191 (2015) 512 – 518
Procedia Social and Behavioral Sciences

WCES 2014

# Conceptual Maps and Integrated Experiments for Teaching/Learning Physics of Photonic Devices

Cziprok Claudia Daniela[a,b]*, Popescu F.F.[a], Pop Alexandru Ioan[b], Variu Andrei[b]

[a] *Faculty of Physics, University of Bucharest, 077125, Bucharest–Magurele, Romania*
[b] *"Mihai Eminescu" National College, 440014, Satu Mare, Romania*

**Abstract**

This paper presents the experimental approach and an example of using conceptual maps as a method based on constructivist mode of learning, teaching and researching knowledge of quantum Physics, using photonic devices. Understanding the Planck relationship, which links energy and frequency as a result of quantification of the energy, is a crucial step. It is one of the most famous examples of the corpuscular nature of light, which led to the development of quantum mechanics in the early 20th century, and whose explanation is still the standard in teaching Physics in high school. The paper also presents the verification of Einstein's theory and determination of Planck's constant using electroluminescent phenomenon for LEDs of different colours. Conceptual maps are a powerful tool not only for perceiving, representing and achieving knowledge, but also for creating new knowledge. It is essential helping students to understand that all concepts are somehow related to each other. Selecting cross-links as specific as possible and identifying the most appropriate linking words to connect concepts are crucial aims. CmapTools software tool can serve as a basis for a new kind of integration of Internet resources and all classroom experiences, inside Physics laboratories, and outside them. If it is used in conjunction with conceptual maps designed to support learning, it provides a new educational model.

Selection and peer-review under responsibility of the Organizing Committee of WCES 2014

*Keywords:* Conceptual maps; Einstein's theory; Planck's constant; Photonic Devices;

## 1. Introduction

Society has a great need not only for a few technically trained people, but for a large group of individuals who understand science. If we want to reach a substantial fraction of our students, we must pay much more attention to

* Cziprok Claudia Daniela. Tel.: +04074-017-3055
*E-mail address*: clcziprok@yahoo.com


Selection and peer-review under responsibility of the Organizing Committee of WCES 2014
doi:10.1016/j.sbspro.2015.04.284

how students learn and how they respond to our teaching. We must treat the teaching of physics as a scientific problem. Cognitive studies focus on how people understand and learn. What we are teaching is important, but it must be viewed in the context of what our students learn. Physics, as a discipline, requires learners to employ a variety of modalities (methods of understanding) and to translate from one to the other – words, tables of numbers, graphs, equations, diagrams, maps. Physics requires the ability to use mathematics and to be able to go from the specific to the general and all the way back. This makes learning Physics particularly difficult for many students. One of our goals should be having our students understand this, being able to identify their own strengths and weaknesses, and while building on the former, strengthen the latter (Redish, 1994). Physics is an important subject in the secondary school curriculum because it helps the learners to apply the principles, acquired knowledge and skills to construct appropriate scientific devices from available resources. In addition it prepares learners for scientific and technological vocations (Wambugu, Changeiywo & Ndiritu, 2013).

### *1.1. Instructional design*

At its base, the constructivist movement in education involves curriculum reform, a rethinking of what it means to know something. A constructivist curriculum is reflected in many of the teaching models. Thus, if a commitment is made toward rethinking curriculum to expand the roles of knowledge construction and learning communities, then a corresponding commitment needs to be made in rethinking learning activities. Thinking of instructional design as a technology would lead us to think that a situation gets analyzed. It leads to a technical fix to be implemented and either to a measured solution to the problem or a revision in the fix for the next cycle of intervention. A situated view of instructional design would lead to a different process:

1. A learning community examines and negotiates its own values, desired outcomes, and acceptable conventions and practices.
2. The learning community plans for and engages in knowledge-generating activities within the established framework of goals, conventions, and practices.
3. Members of the learning community, including both teachers and students, observe and monitor learning and make needed adjustments to support each other in their learning activities.
4. Participants occasionally re-examine negotiated learning goals and activities for the purpose of improving learning and maintaining a vital community of motivated learners.

This may lead to new goals and methods and cultural changes at all levels, from cosmetic to foundational (Wilson & Cole, 1996).

We decided to use the experimental approach and an example of using conceptual maps as a method based on constructivist mode of learning, teaching and researching knowledge of quantum Physics, using photonic devices.

### *1.2. Conceptual mapping*

The act of instruction can be viewed as helping the students unravel individual strands of belief, label them, and then weave them into a fabric of more complete understanding. Rather than denying the relevancy of a belief, teachers might do better by helping students differentiate their present ideas from and integrate them into conceptual beliefs more like those of scientists (Bransford, Brown & Cocking, 2002). Conceptual maps are a powerful tool not only for perception, representation and achieving of knowledge, but also for creating new knowledge. Visual representations of the links between concepts commonly used in a lesson allow transmission of new content for students with different prior knowledge (Cziprok, Miron & Popescu, 2013). Concept mapping is most useful if it is used as a study tool over the course of instruction. It is expected that concept maps help students to overcome difficulties by integrating them into well-structured cognitive frameworks. Concept mapping involved students who use concept maps as a training method relating new information to prior knowledge resulting in meaningful learning and consequently higher achievement. Concept maps help students to answer the questions (Karakuyu, 2010). Since a good understanding of concepts seems to be a prerequisite for expert problem solving, much effort has gone into the identification of fundamental concepts and student difficulties in a variety of specific areas (Redish, & Steinberg, 1999).

### *1.3. Integrated Experiment*

The effect of electromagnetic radiation causing electrons to be emitted from a metallic surface is called photoelectric effect. Historically, it was first described by Heinrich Hertz in 1887. During the following experiments it turned out that the wave theory which was predominant at that time could not explain all important experimental results. Today's well-known quantum mechanical interpretation of the photoelectric effect is based on Einstein's thoughts around 1905 involving the reviving idea of light as flow of particles (Hoeh, 2005). Understanding the Planck relationship, which links energy and frequency as a result of quantification of the energy, is a crucial step. It is one of the most famous examples of the corpuscular nature of light, which led to the development of quantum mechanics in the early 20th century, and whose explanation is still the standard in teaching Physics in high school. We believe that hands-on experiment and practical activities in Physics, improve students' learning, help practical skills development, problem solving, analytical skills, and positive attitudes towards science. Hands-on experiments offer students concrete experiences and opportunities to confront misconceptions. There is no replacement for student's hands-on experience as far as instrumentation and physical processes are concerned. No doubt, through hands-on experiments, students become active learners and acquire scientific skills and knowledge in a meaningful context (Benson & Nkiruka, 2013).

## 2. Methodology

We chose to implement, by means of conceptual map and CmapTools software, the method based on constructivist mode of learning, teaching and research knowledge of quantum Physics, using photonic devices, studied in the fourth year of high school. Students were given access the IHMC Public C-maps and were familiarized with the workings of this program, see a print screen on http://tinyurl.com/ojj66wc. At first, as advanced organizers, we have completed together, from the concepts about semiconductors, energy bands structure (http://tinyurl.com/oxut98z), p-n junction and electronic devices, a conceptual map with resources, which can be viewed at http://tinyurl.com/pygmew8, preceding hands-on experiment with LEDs. Understanding the Planck relationship, which links energy and frequency as a result of quantification of the energy, is a crucial step. It is one of the most famous examples of the corpuscular nature of light, which led to the development of quantum mechanics in the early 20th century, and whose explanation is still the standard in teaching Physics in high school. Students also built conceptual maps, which were defined and explained the photoelectric effect and its laws, which can be viewed at http://tinyurl.com/na3yejg and http://tinyurl.com/q5pn99l. The majority of students did not understand the terms frequency and intensity in relation to the "bird on a wire" analogy (Fletcher, & Johnston, 1999). This experiment makes a connection between elements of quantum Physics and the physical structure and properties of semiconductor materials through which there occurs a transformation of electrical energy into light energy. Most students can "discover" the energy band model for a solid when they are asked to create an acceptable set of energy levels to explain the continuous spectrum of an LED. They are also able to predict the spectrum and turn-on voltage of an LED given its energy band diagram. (Rebello & Zollman, 1999).

### *2.1. Theoretical considerations*

Light Emitting Diodes (LEDs) are semiconductor devices characteristically defined by their ability to emit electromagnetic radiation in the visible spectrum when a potential is applied to the semiconductor materials (Chang, Chen, Kuo, & Shen, 2010). A diode is a circuit element that only allows current to flow in one direction. It is most often constructed out of semiconducting materials. A semiconductor is a material which contains atoms in a crystalline state. Its properties are given by the electrons on the most exterior orbits. Atoms have possible energy states which are normally represented by levels. In a semiconductor, these are wider, forming bands. There are two important energy levels: the valence band (low energy) and the conductive band (high energy). These are separated by a so-called forbidden band, which could contain no electrons. Electrons can either inhabit the valence band or the conductive band, and could not exist anywhere between them. When an electron receives energy from outside the system, it jumps onto the conductive band, leaving behind a positive charge - a "hole". All physical systems tend to exist on a minimal energy level, so the electrons tend to fall down to the valence band, emitting the extra energy. These electron-hole recombination's can be radiative (emitting light) or non-radiative (increasing the temperature of the system). These two phenomena occur permanently in all diodes. A LED (Light Emitting Diode) is a diode in which the radiative recombinations predominate. Under the effect of a difference in potential **U**, if the energy **eU** is high enough, the electron (with elementary charge **e**) will jump from the valence band to the conduction band. There exists a value $\mathbf{U_{threushold}}$ at which, in good approximation, only a photon is emitted. Seeing as energy is conserved, when it falls back, the emitted photon will have the same energy. Einstein has shown (1905) that the energy of a photon is.

$$\varepsilon = \mathrm{h} \cdot \nu \qquad (1)$$

Where ε is the energy of a quantum of light, ν is its frequency and h is Planck's constant.
The next logical conclusion is that:

$$\mathrm{e} \cdot \mathrm{U}_{\mathrm{threshold}} = \mathrm{h} \cdot \nu \qquad (2)$$

Planck's constant **h**, calculated in 1900 by Max Planck, is one of the fundamental values in quantum Physics.
Most students are able to understand the concept that the energy of the spectral line is related to the difference in energy between two levels and not the values of the levels themselves (Escalada, Rebello, & Zollman, 2004).

### *2.2. Built circuit*

This experiment makes a connection between elements of quantum physics and physical structure and properties of semiconductor materials which produce a conversion of light energy into electrical energy. For our experimental study of the effect of luminescence caused by electric current in a semiconductor, we used the Built circuit (potentiometer, resistor Rp, switch between LEDs); Power source (we were using a Rotary Switch Adaptor and selected 12V for the output voltage); Digital Multimeter DT-830B; the resistor Rp has the color code: red, red, red, gold.

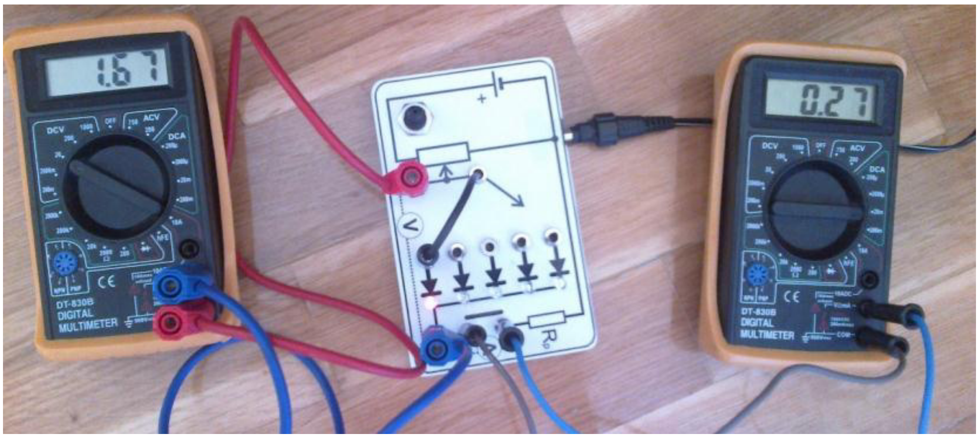


Fig 1. Experimental devices (see on http://tinyurl.com/mt9zmtl)

### *2.3. Records, data processing*

The experimental determination of Planck's constant is then easily obtained by determining the wavelength of the emitted radiation from an LED and applied voltage over the LED concurrently (Eagan, 2011). For each LED we have determined the interval of wavelengths (1) by other means (diffraction and interference), but these values can be considered known, as they are production characteristics. We used the maximum value as it corresponds to the minimum energy of the photon (see Table 1).

Table 1. Associated wavelengths used LEDs

| Color | Wavelength (minimum) | Wavelength (maximum) |
|---|---|---|
| Blue | 419 | 536 |
| Green | 493 | 578 |
| Yellow | 611 | 663 |
| Orange | 645 | 696 |
| Red | 676 | 732 |

We have determined $\mathbf{U_{threushold}}$ by three of the possible methods: from the current/voltage (IV) characteristic, (see Table 2) by considering that $\mathbf{U_{threushold}}$ is reached when the current reaches 0.01mA (see Table 3), and by watching the LEDs (in a dark environment) and slowly increasing the voltage until they started emitting light (see Table 4). By employing the first method, for each LED (red, orange, yellow, green, and blue) we graphed I (U) by increasing the voltage using the built-in potentiometer, and reading the current from the ammeter. From this we extracted $\mathbf{U_{threushold}}$: considering that the rounded part of the graph (see Fig. 2, on http://tinyurl.com/lj5j2c8) is due to thermally-induced current leakage. We ignored it and calculated the point in which the rapidly rising part (approximated with a straight line) of the graph intersects the X axis.

In equation (2) we replaced $\boldsymbol{\nu} = \mathbf{c}/\boldsymbol{\lambda}$ and we separated the terms, so $\mathbf{h} = (\boldsymbol{\lambda} \cdot \mathbf{e} \cdot \mathbf{U_{threushold}})/\mathbf{c}$

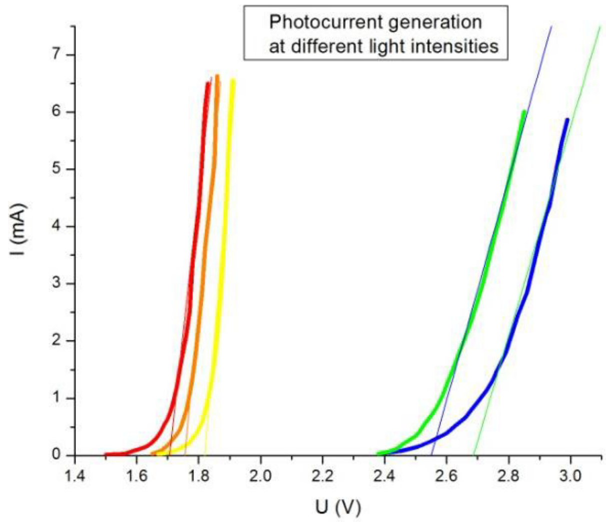


Fig.2. The voltage plotted against the photocurrent for different light intensities.

Table 2. Values obtained by the first method

| Color | U threshold | Wavelength | h/(10 ^-34) | average h/(10 ^-34) | delta h/(10 ^-34) | error |
|---|---|---|---|---|---|---|
| - | V | nm | J*s | J*s | J*s | % |
| Blue | 2.54 | 536 | 7.83 | | 0.82 | 12 |
| Green | 2.71 | 578 | 7.75 | | 0.73 | 10 |
| Yellow | 1.82 | 663 | 6.43 | 7.01 | 0.58 | 8 |
| Orange | 1.75 | 696 | 6.49 | | 0.52 | 7.5 |
| Red | 1.68 | 732 | 6.56 | | 0.45 | 6.5 |

By using the second method we used the values of $\mathbf{U_{threushold}}$ that we read when I was measured as being 0.01 mA.

Table 3. Values obtained by the second method

| Color | U threshold | Wavelength | h/(10 ^-34) | average h/(10 ^-34) | delta h/(10 ^-34) | error |
|---|---|---|---|---|---|---|
| - | V | nm | J*s | J*s | J*s | % |
| Blue | 2.32 | 536 | 7.15 | | 0.90 | 14.5 |
| Green | 2.28 | 578 | 6.52 | | 0.27 | 4.3 |
| Yellow | 1.60 | 663 | 5.66 | 6.25 | 0.59 | 9.5 |
| Orange | 1.60 | 696 | 5.94 | | 0.31 | 5 |
| Red | 1.53 | 732 | 5.97 | | 0.27 | 4.5 |

By employing the third method, we have found:

Table 4. Values obtained by the third method

| Color | U threshold | Wavelength | h/(10 ^-34) | average h/(10 ^-34) | delta h/(10 ^-34) | error |
|---|---|---|---|---|---|---|
| - | V | nm | J*s | J*s | J*s | % |
| Blue | 1.95 | 536 | 6.01 | | 0.76 | 14.5 |
| Green | 1.77 | 578 | 5.06 | | 0.19 | 3.6 |
| Yellow | 1.45 | 663 | 5.13 | 5.25 | 0.12 | 2.3 |
| Orange | 1.34 | 696 | 4.97 | | 0.27 | 5.2 |
| Red | 1.30 | 732 | 5.07 | | 0.17 | 3.3 |

## 3. Conclusion

We have determined h to be $h = 6{,}25 \cdot 10^{-34}\,Js\ \mp 7{,}5\,\%$ by using the second method. The other determined value: $h = 7{,}01 \cdot 10^{-34}\,Js\ \mp 8{,}8\,\%$. As the second method yields a value of h closer to its real value and a lower error, we recommend its usage. This experiment proves that important information can be obtained without using expensive materials. It is easy for the experiment to be redone in high schools and it is a very good way to help students understand some of the phenomena. It is quite fascinating to see such fundamental phenomena having such an easily observable manifestation.

## References


Benson, A. A., Nkiruka C. (2013). Improving Students' Learning Outcomes In Practical Physics, Which Is Better? Computer Simulated Experiment or Hands-On Experiment*? IOSR Journal of Research & Method in Education*, *2*(6), 18-26.

Bransford, J.D., Brown, A.L. & Cocking, R.R. (eds.), (2002). *How People Learn, Expanded Edition*. Washington, DC: Natl. Acad. Press. Available at: http://www.csun.edu/~SB4310/How%20People%20Learn.pdf

Chang, S.H., Chen, M.L., Kuo, Y.K., & Shen, Y.C. (2010). *International IGIP-SEFI Annual Conference*, Trnava, Slovakia.

Cziprok, C.D, Miron, C., & Popescu, F.F. (2013). *The Proceedings of the 9th International Scientific Conference eLearning and software for Education*, Bucharest, Romania.

Eagan, R. (2011). *Experimental Determination of Planck's constant*. The Pennsylvania State University, University Park, Pennsylvania 16802.

Escalada, L. T., Rebello, N. S., & Zollman, D. A. (2004). Student Explorations of Quantum Effects in LEDs and Luminescent Devices. *The Physics Teacher, 42*, 173-179.

Fletcher, P. & Johnston, I. (1999). Quantum Mechanics: Exploring Conceptual Change, *National Association for Research in Science Teaching*.

Hoeh, M. (2005). *Determination of Planck's constant by photoemission*, Imperial College London

Karakuyu, Y. (2010). The effect of concept mapping on attitude and achievement in a physics course. *International Journal of the Physical Sciences*, *5*(6), 724-737.

Rebello, N.S., Zollman, D.A. (1999). Conceptual Understanding of Quantum Mechanics after Using Hands-On and Visualization Instructional Materials, *National Association for Research in Science Teaching*.

Redish, E.F. (1994). The Implications of Cognitive Studies for Teaching Physics, *American Journal of Physics*, *62*(6), 796-803.

Redish, E.F., & Steinberg, R.N. (1999). Teaching Physics: Figuring Out What Works, *Physics Today*, *52*, 24-30.

Wambugu, P.W., Changeiywo, J.M., & Ndiritu, F.G. (2013). Effects of Experiential Cooperative Concept Mapping Instructional Approach on Secondary School Students'achievement in Physics in Nyeri County, Kenya, *Asian Journal of Social Sciences & Humanities*, *2*(3), 279-296

Wilson, B. & Cole, P. (1996). *Cognitive Teaching Models. Handbook of Research in Instructional Technology*, David H. Jonassen, editor, New York: Scholastic Press.