Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: Francesca Santonocito *et al* 2018 *J. Phys.: Conf. Ser.* **1076** 012009

IOP Conf. Series: Journal of Physics: Conf. Series **1076** (2018) 012009 doi:10.1088/1742-6596/1076/1/012009

From led light signboards to the Planck's constant

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Abstract. Recent studies have highlighted an alarming decline in young people's interest towards the study of scientific subjects, often considered interesting but not easily understood and appreciated by students. In particular, the introduction of Modern Physics (MP) key topics at secondary school level is a difficult and complex task because MP involves abstract ideas and requires a strong mathematical background.
In this communication we present and discuss the results of an inquiry-based teaching/learning path aimed at surmounting the difficulties of an exclusively theoretical approach to the introduction of MP topics. In particular, we planned and realized an inquiry-driven learning environment where about 20 students, from a second-year class of a vocational school, were involved in the discovery of the Planck's constant and brought closer to MP. The work, carried out as a cross-disciplinary module, has involved Physics and Technological Laboratory. The task given to the students was the design of an illuminated sign, efficient from the energetic point of view, flexible and attractive. Through a 'guided inquiry', the students evaluated the different solutions, developed their critical thinking and decided to implement them with LED diodes. Planck's constant has been determined by two methods of analysis of the experimental data and satisfactory values have been obtained. Our results suggest that an inquiry-based teaching/learning path, can constitute a successfully teaching approach to effectively engage students into an active learning of the MP. The described learning activity provided students with opportunities to develop a large range of complementary skills such as working in groups, synthesis, interpretation and evaluation of the experimental data, experience of open-ended problems solving and other cross-disciplinary abilities.

1. Introduction

In the last decades, physics educators proposed many teaching strategies to introduce MP key topics at secondary school level, concluding that both teaching and learning MP concepts is difficult because they contain abstract ideas and require a strong mathematical background (Johnson *et al.* 1998, Kroemer 1994, Ireson 2000, Muller & Wiesner 2001, Olsen 2002, Etkina 2010). Recent reports showed that one of the factors that influence the increase of interest, of motivation and of a positive attitude towards the study of Physics, is represented by the didactic methods used within the teaching-learning process (Global Science Forum 2008).Thus, to the difficulty of teaching MP often adds a wrong teaching methodology implemented by educators, who prefer standard class lectures and mathematical calculations. In order to reach out the teachers and to overcome these problems the Italian Ministry of Education has promoted the development of specific courses for in-service teachers, who should be trained to help the students to acquire scientific and technical skills also in Modern Physics (Pospiech 2000; Michelini *et al.* 2000, 2004a, 2004b; Francaviglia *et al.* 2012). After attending one of these training courses, organized by the Regional Office for Secondary Education, jointly with a team of researchers at the Department of Physics and Chemistry, University of Palermo, within the PLS Project (Persano Adorno *et al.* 2017), two of our most relevant changes were related to: i) the discovery of interesting laboratory experiences of Modern Physics exploitable also at upper secondary school level (Petri & Niedderer 1998, Indelicato *et al.* 2013, Persano Adorno & Pizzolato 2015); ii) the knowledge of a new teaching methodology, the IBSE (Inquiry Based Science Education) approach (Herron 1971, Bybee 1993, McDermott 1996, National Research Council 2000, Llewellyn 2002, Banchi & Bell 2008), that can constitute a successfully teaching approach to effectively engage students into an active learning of the MP.

In this work we present the results of an inquiry-based teaching/learning path designed to overcome the difficulties of an exclusively theoretical approach to the introduction of Modern Physics (MP) topics. In particular, we planned and realized an inquiry-driven learning environment where about 20 students, from a second-year class of the vocational school "E. Fermi-F. Eredia" of Catania, were involved in the discovery of the Planck's constant, by following the steps indicated by Indelicato et al., 2013. The work, carried out as a cross-disciplinary module, has involved Physics and Technological Laboratory.

2. IBSE: why inquiry?

Inquiry-based Science Education (IBSE) – *learning through questioning* – is a teaching methodology that aims to promote the active participation of the students in the classroom through the use of scientific inquiry, towards a more direct understanding of "how" science effectively produces new knowledge. Inquiry is the "intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Byrnea & Johnstone 1987, NRC 2000, Llewellyn 2002, NRC 2012). Within an inquiry environment, the laboratory is not considered the place where students only observe experiences carried out by others or attend fruitless demonstrations of the validity of physics laws previously introduced by the teacher theoretically. The students are personally involved in experimental activities, facing problematic situations that requires reasoning efforts, in order to be solved effectively. Moreover, the laboratorial activity must be preceded by a preliminary phase characterized by posing scientifically relevant questions, designing procedures and be followed by a final critical evaluation of obtained results. Finally, scientific practices also include the sharing of ideas with peers, drawing explicatory models, supporting conclusions and making choices based on arguments and evidences.

The teaching strategies involved in inquiry approaches are grounded on the viewpoint that students are active thinkers, who construct their own understanding from interactions with phenomena, the environment, and other individuals. In inquiry-based learning, the students are engaged in identifying scientifically oriented questions, planning investigations, collecting data and evidences in laboratory and/or real life situations, building descriptions and explanation models, sharing their findings and eventually addressing new questions that arise. Depending on the amount of information and support provided by the teachers, the learners may be involved in a structured/guided inquiry or OI (Schwab 1962, Herron 1971, Banchi & Bell 2008). Generally, in structured inquiry the questions and procedures are provided by the teacher, and students generate their own explanations, supported by the evidence they have collected. In guided inquiry the teacher provides the students with only the research questions, and the students design the procedures to find reasonable answers and/or test the resulting explanations. In OI-based instruction, the teacher takes the delicate role of defining the context for inquiry, stimulating the students to derive their own questions, design and carry out independent investigations, construct coherent explanations, share their findings. This level of inquiry requires the highest capacity of scientific reasoning.

3. Activity description

The task assigned to the students was the design of an illuminated sign, efficient from the energetic point of view, flexible and attractive. The work, carried out as a cross-disciplinary module, has involved Physics and Technological Laboratory during 6 hour for week, lasting 8 weeks. Teachers acted as knowledge facilitators, providing support or materials, during all the teaching /learning process. The learning activity consisted of two different phases: the first one conducted the learners to the design and realization of the own signboard, causing them to reflect on the diode LED response; the second one, was focused on the calculation of the Plank's constant, mainly involving collection and analysis of the data. Each phase followed the 5E cycle (ENGAGE, EXPLORE, EXPLAIN, EXTEND, EVALUATE) in order to effectively develop student critical thinking and to help students to explore and evaluate their learning (Bybee 1993) (see Fig. 1).

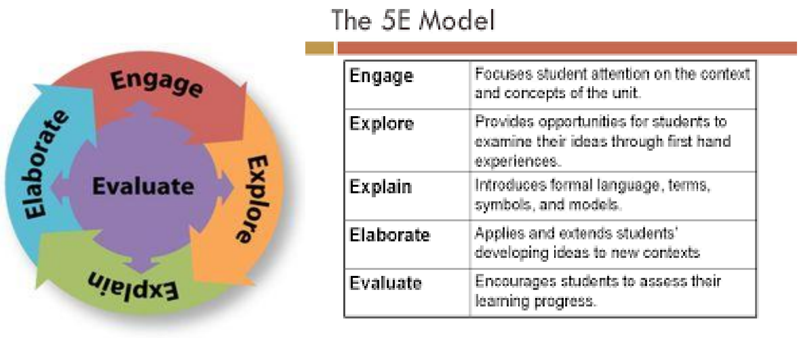

Fig. 1. The Inquiry 5E learning cycle

Phase 1

a. The engagement: the design of an illuminated sign

Students were asked to work in groups and to perform scientific investigations devoted to the design, realization and testing of illuminated signs, attractive and having physical characteristics able to maximize the efficiency. Through a *guided inquiry* environment, the students evaluated the different solutions, also by using internet resources to gather literature, developed their critical thinking and decided to implement the illuminated sign by using LED diodes.

b. Execution of experiments 1

Students were stimulated to carry out their own experimental work in the most independent way they were feeling confident to do it. During the first session in laboratory, our students discovered the laws governing the electrical connections. In particular, they learned how to connect the LEDs and determined the load resistance to avoid the LED "burning". Then each student designed its light signboard and carried out it. Students used the logbooks to note the followed procedure, the difficulties encountered throughout the activity and the changes they made during the inquiry process. Figs 2 and 3 refer to this phase.

Fig. 2. Students learn how connect LED

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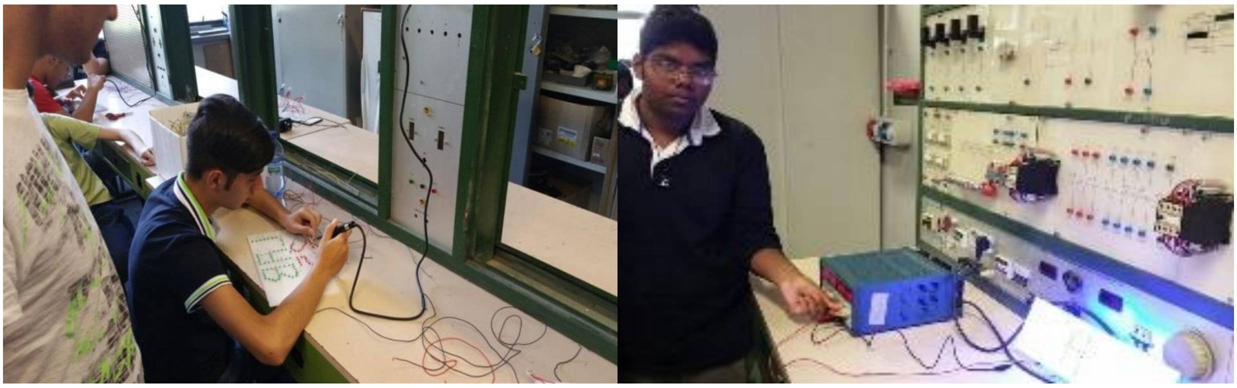

Fig. 3. Students realizing own light signboards

c. Cooperative work in the classroom (Explain, Elaborate, Evaluate)

During the cooperative work in the classroom the students commented the differences in the I-V characteristic curve between ohmic conductors and LED diodes, asking several interesting questions. In particular, they analyzed the collected data and built the I-V characteristic (see Fig. 4).

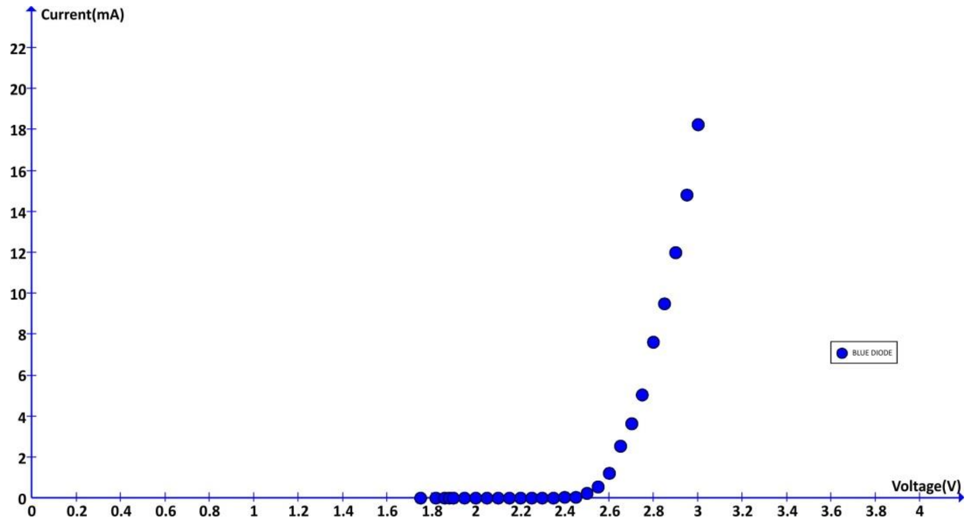

Fig. 4. The I-V curve in our Blue LED, λ = 430 nm

Phase 2

a. Frontal lesson (including video-projection, multimedia material, data sheets, discussion)

A deep reflection about the atomic models gave to the students the answers to the questions generated during the Phase 1. Moreover, the Bohr's model and the Einstein explanation of the photoelectric effect led the learners to the discovery of the Planck's constant. The approach with atomic model has allowed to discover the mechanism of the working of a LED diode They learned that a diode emits light when it reaches a threshold voltage and uncovered the "new" law

$$eV_s = hv$$

where e is electron charge, V_s is threshold voltage, h is Planck's constant and v is frequency. After this step the new challenging task of our students was the measurement of the Planck's constant.

b. Laboratorial activity 2

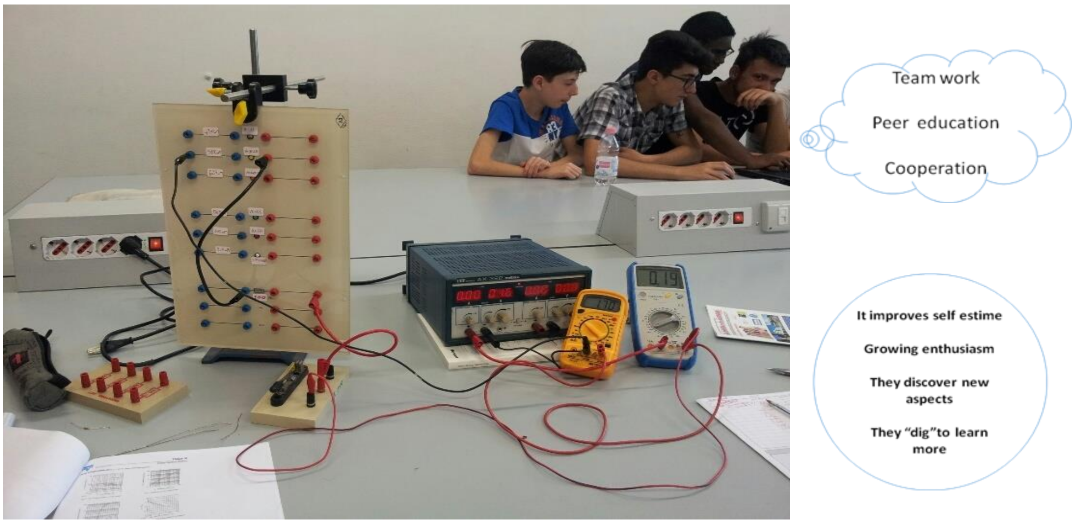

Fig. 5. Our experimental setup and students working in team

Students evaluated the different systems for the measurement of Planck's constant, making use of Internet resources gathered in literature. They planned how to make it during the technological laboratorial activities at the school. The students selected diodes with specific characteristics and purchased them. The experimental set-up was home-made by the students after they acquired critical thinking on it (see Fig. 5). In particular, they designed and carried out an apparatus formed by a set of six LEDs of different colors, with an external nominal load resistor of 100 Ω to prevent too high currents, a standard low-voltage power supply and two digital multimeters of standard quality. The electric circuit is shown in figure 6.

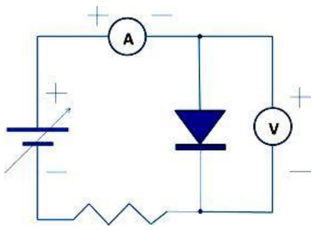

Fig. 6. The electric circuit of our experimental set-up

The students observed and registered the bias voltage applied to the LED and the relative currents values. The I-V curves carried out for the employed LEDs are shown in Fig. 7.

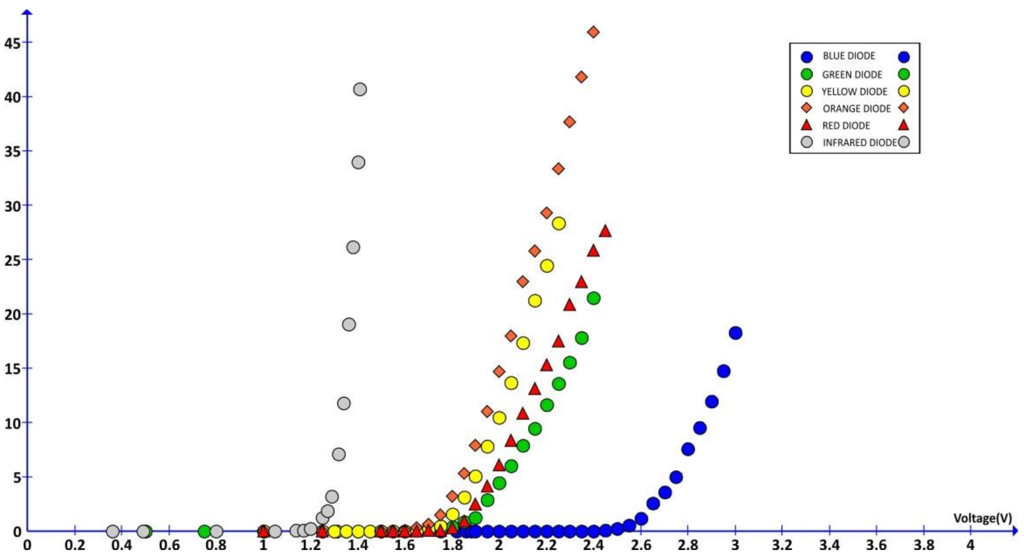

Fig. 7. I-V characteristic curves carried out for the employed LEDs

c. Cooperative data analysis and peer to peer work in the classroom

The analysis of data gathered from the I-V curves has raised several problems, mainly due to the fact that the threshold voltage was not well-defined. We cooperatively discussed on this problem and reflected on it. After long discussion, in order to overcome the problems of the identification of the "turn-ON" voltage, the students decided to follow two different criteria to determine it:

- to take the value of the bias voltage when the electrical current starts to be different from zero and LED was "turned ON" (*Method 1*);
- to extrapolate a small part of the nearly exponential curve linearly to zero (*Method 2*).

Analysis of the experimental findings

About a half of the students decided to use the first method for the determination of the of the "turn-ON" voltage and in table 1 we report the data collected by using this method.

Table 1. Threshold voltage, Energy, Planck's constant value f or the six LED (characterized by their wavelength λ and frequency ν) obtain by means of *Method 1*

Wave length λ **[nm]**	**Frequency** ν **[10^{14}Hz]**	**Threshold Voltage** V_s **[V]**	**Energy** **E [10^{-19}J]**	**Planck's Constant** **h [10^{-34} Js]**
430	6.98	2.50 ± 0.01	4.00	5.73
565	5.31	1.85 ± 0.01	3.51	6.61
590	5.08	1.70 ± 0.01	2.72	5.35
627	4.78	1.65 ± 0.01	2.64	5.52
700	4.29	1.73 ± 0.01	2.8	6.52
850	3.53	1.20 ± 0.01	1.87	5.29

Afterwards, the students calculated the average value of Planck's constant and its standard deviation Δh, obtaining **h = (5,84 ± 0,59)10^{-34} Js**.

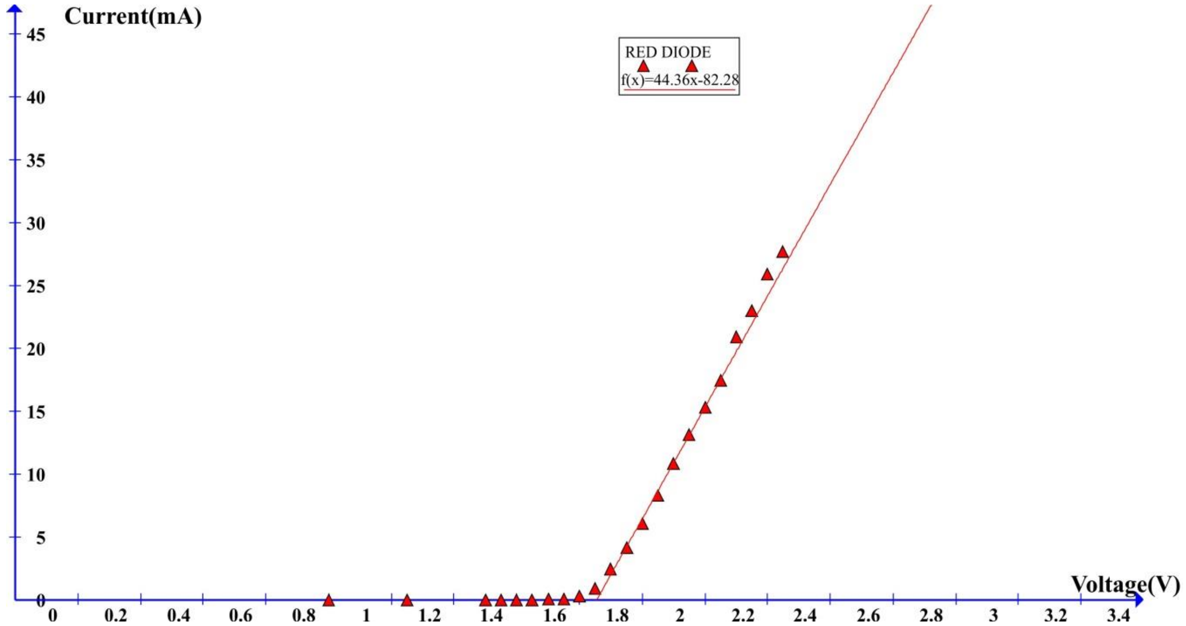

Fig. 8. Threshold voltage determined by means of a linear regression (*Method 2*)

The sample of students deciding to use the *Method 2*, carried out the best fit of the data in order to obtain the threshold voltage V_s (see Fig. 8). Afterwards, by means of a statistical analysis, they calculated the value of the Planck's constant for each LED. They also calculated the uncertainty for each value obtained. The values of Planck's constant together with their error bars are shown in Fig. 9. During this relevant phase of the cooperative work, the students learned the significance of linear regression of the experimental data and how to calculate the error attributable to each measure

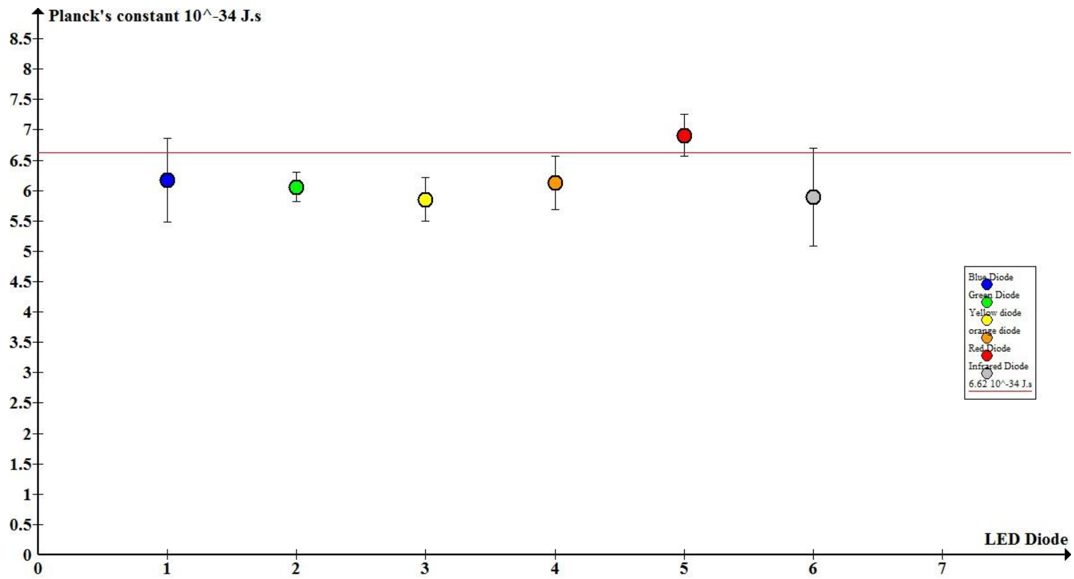

Fig. 9. Experimental values of Planck's constant together with their error bars, obtained with *Method 2*

In table 2 we report the data collected by using the *Method 2*

Table 2. Threshold voltage, Energy, Planck's constant value f or the six LED (characterized by their wavelength λ and frequency ν) obtain by means of *Method 2*

Wave length λ [nm]	**Frequency ν [10^{14} Hz]**	**Threshold Voltage Vs ± ΔV_s [V]**	**Energy E ± ΔE [10^{-19}J]**	**Planck's Constant h ± Δh [10^{-34} Js]**
430	6.98	2.69 ± 0.30	4.30 ± 0.48	6.17 ± 0.69
565	5.31	1.91 ± 0.08	3.06 ± 0.15	6.06 ± 0.24
590	5.08	1.86 ± 0.11	2.98 ± 1.81	5.85 ± 0.36
627	4.78	1.83 ± 0.13	2.93 ± 0.21	6.12 ± 0.44
700	4.29	1.85 ± 0.05	2.96 ± 0.15	6.91 ± 0.35
850	3.53	1.30 ± 0.18	2.08 ± 0.28	5.89 ± 0.81

Also in this case, the students calculated the average value of Planck's constant and its standard deviation Δh, obtaining **h = (6,16 ± 0,39)10^{-34} Js**.

At the end of the cooperative work, the students by means of peer to peer discussion in the classroom, compared the values for the Planck's constant obtained by using the two methods.

Both results are compatible with the accepted value of the Planck constant, but only that obtained with the second method stays within approximately the 10% of it, which is a reasonable result for an educational measurement.

4. Discussion and conclusion

Here we presented and discussed the outcomes of an inquiry-based teaching/learning path aimed at surmounting the difficulties of an exclusively theoretical approach to the introduction of MP topics in a vocational secondary school. Students learned how to conduct a scientific research activity, starting from an initial collection of information (literature), and moving across a planning phase, the design and realization of measurements, gathering and analyzing data, the formulation of hypothesis and modeling, drawing conclusions.

At the end of laboratorial activities we administered an open-ended questionnaire about basic MP arguments both to the students involved in this workshop (experimental group) and to a sample of students characterized by the same age and curricular instruction, but belonging to a different class not involved in this learning experience (control group). The comparison between the questionnaire marks obtained by the two student groups shows that the students which have attended the inquiry-based laboratorial learning path have achieved considerably higher scores both in terms of concept understanding and abilities in the synthesis, interpretation and evaluation of experimental data.

More important, at the end of this module the students acquired much more confidence in their approach to the study of physics, even under the point of view of their social skills, as a direct result of the teamwork carried out during the exploration phase. The presented laboratorial learning sequence has enhanced the student outcomes also in terms of motivation, interest, reflective participation, critical observation and discovery learning. Information about the student affective development and motivation to learn was achieved by means of structured interviews based on the Intrinsic Motivation Inventory, with specific items adapted to our study (Jang *et al.* 2016). Moreover, the learners have enthusiastically attended a summer Physics school held at the Scientific Lyceum "A. Volta" of Caltanissetta where they presented and shared with students of other high-schools the whole activity.

For the sake of saving space, we cannot report here the whole analysis of the student answers to both the questionnaire and satisfaction survey. The full analysis and results will be the subject of a forthcoming paper.

Fig. 10. A group of our students presented this laboratorial work to the students of different high-schools during a summer Physics school

In conclusion, the proposed inquiry-based activity provided students with the opportunity to develop a large range of complementary skills such as working in groups, synthesis, interpretation and evaluation of the experimental data, experience of open-ended problems solving and other cross-disciplinary abilities. Moreover this activity has had a positive impact on students' attainments, with an even stronger impact on the students with lower levels of self-confidence and those from disadvantaged backgrounds.

References

Banchi H. & Bell R. (2008) The many levels of inquiry. *Science and Children* **46**(2), 26-29.

Bybee R.W. (1993) An instructional model for science education. In *Developing Biological Literacy*, Biological Sciences Curriculum Study, Colorado Springs, CO.

Byrnea M.S. & Johnstone A.H. (1987) Critical Thinking and Science Education. *Studies in Higher Education* **12**(3), 325-339.

Etkina E. (2010) Pedagogical content knowledge and preparation of high school physics teachers. *Physical Review Special Topics Physics Education Research* **6**, 020110.

Foti A. & Gianino C. (1999) Elementi di analisi dei dati sperimentali-Liguori editori.

Francaviglia M., Lorenzi M.G., Michelini M. & Stefanel A. (2012) IDIFO3 – teachers formation on modern physics and mathematical foundations of quantum physics: a cross sectional approach. *Journal of Applied Mathematics* **5**, 231-240.

Global Science Forum (2008) *Encouraging student interest in science and technology studies*.

Herron M.D. (1971) The nature of scientific enquiry. *School Review* **79**, 171-212.

Indelicato V., Rocca P., Riggi F., Santagati G. & Zappalà G. (2013) Analysis of LED data for the measurement of Planck's constant in the undergraduate laboratory. *European Journal of Physics* **34**(4), 819-830.

Ireson G. (2000) The quantum understanding of pre-university physics students. *Physics Education* **35**, 15-21.

Jang H., Reeve J. & Halusic M. (2016) A New Autonomy-Supportive Way of Teaching That Increases Conceptual Learning: Teaching in Students' Preferred Ways. *The Journal of Experimental Education* **84**(4), 686-701.

Johnson I.D., Crawford K. & Fletcher P.R. (1998) Student difficulties in learning quantum mechanics. *International Journal of Science Education* **20**, 427-446.

Kroemer A. (1994) Investigating quantum physics in the high schools environments. *Physics Education* **56**, 127-139.

Llewellyn D. (2002) *Inquiry Within: Implementing Inquiry-based Science Standards*. Corwin Press Inc., Thousand Oaks, CA.

McDermott L.C. & Physics Education Group at the University of Washington (1996) *Physics by Inquiry*, John Wiley & Sons, New York.

Michelini M., Ragazzon R., Santi L. & Stefanel A. (2000) Proposal for quantum physics in secondary school. *Physics Education* **35**, 406-410.

Michelini M., Ragazzon R., Santi L. & Stefanel A. (2004a) Implementing a formative module on quantum physics for pre-service teacher training. In *Quality Development in the Teacher Education and Training* (Michelini M., ed.), Forum, Udine, pp. 429-435.

Michelini M., Ragazzon R., Santi L. & Stefanel A. (2004b) Discussion of a didactic proposal on quantum mechanics with secondary school students, *Il Nuovo Cimento* C **27**, 555-567.

Michelini M. (2010) *Progetto IDIFO. Fisica Moderna per la Scuola. Materiali, aspetti e proposte per l'innovazione didattica e l'orientamento*, MIUR-PLS-UniUD, Udine.

Muller R. & Wiesner H. (2001) Teaching quantum mechanics on an introductory level, *American Journal of Physics* **70**, 200-209.

National Research Council (NRC) (2000) *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, The National Academies Press, Washington DC.

National Research Council (NRC) (2012) *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, The National Academies Press, Washington, DC.

Olsen R.V. (2002) Introducing quantum mechanics in the upper secondary school: a study in Norway, *International Journal of Science Education* **24**, 565-574.

Petri P. & Niedderer H. (1998) A learning pathway in high-school level quantum atomic physics, *International Journal of Science Education* **20**, 329-347.

Persano Adorno D. & Pizzolato N. (2015) An inquiry-based approach to the Franck-Hertz experiment. *Il Nuovo Cimento* C **38**, 109. DOI: 10.1393/ncc/i2015-15109-y.

Persano Adorno D., Fazio C., Pizzolato N. & Battaglia O.R. (2017) Training Pre-service and In-service Secondary School Teachers: Analysis of Changes in Perceptions About Quantum Physics Concepts and NoS Views. In *Key Competences in Physics Teaching and Learning* **190**, Springer Proceedings in Physics, pp. 165-176.

Pospiech G. (2000) A modern course in quantum physics for teacher education. In *Turning the challenge into opportunities* (Xingkai L. & Kaihua Z., eds.), Guangxi Normal University Press, Guilin, China, pp. 244-248.

Schwab J.J. (1962) The teaching of science as inquiry. In *The teaching of science*, (Schwab J.J. & Brandwein P.F., eds.), Harvard University Press, Cambridge, MA, p. 3-103.