A Physics and Engineering Lab for Primary Teachers at CERN

https://doi.org/10.3991/ijes.v9i3.24753

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Abstract—Major international Research Centers run Continuous Professional Development Courses for Primary Teachers on Science, Technology, Engineering, and Mathematics activities and experiments. The projects and the hands-on workshops inspire teachers through cutting-edge science and technology to influence and spread the research culture to their students in return. The STEM lab in this paper was presented in a CERN program for Greek primary educators teaching Physics and IT. The research focuses on the teachers' electromagnetic lab and was tested by students in the classroom environment for two subsequent years. The results of both labs, of teachers and students, are examined regarding their basic understanding of Physics Laws and scientific research.

Keywords—physics education research, STEM, CERN, hands-on experiments

1 Introduction

1.1 Primary school physics education

Physics education should better start at a very young age [1]. International literature points out that aspirations and desires to pursue a career in STEM professions are established in elementary school [2]. Children can be educated in the process of science at all levels of education, beginning at a very early age [3][4]. Physics education should be an essential component of a learning continuum for all students, regardless of the profession they will pursue later on [1]. It is also essential to teach physics through experimentation. Richard Feynman [5] has put it this way:

> *"The principle of science, the definition, almost, is the following: The test of all knowledge is an experiment. Experiment, itself helps to produce these laws, in the sense that it gives us hints. But also, is needed the imagination to create from these hints the great generalizations …"*

Physics education requires experimental practice in order to enhance the understanding phenomena and processes on the concepts it is based on [6] [7]. The American Association of Physics Teachers [8] indicates that introductory physics laboratory goals should be:

1. The art of experimentation
2. Experimental and analytical skills
3. Conceptual learning
4. Understanding the basis of knowledge in Physics
5. Developing collaborative learning skills.

Addressing modern physics through experimentation [1] with hands-on activities of simple materials is the educational method that presents a more in-depth scientific ideas approach. Therefore, it is crucial to train students' involvement in physics and engineering by presenting how exciting physics is and how it is connected to the learners' daily life starting early at school. Learning about "today's" modern physics and the associated technology stimulates student engagement and excitement; it instills positive attitudes towards physics and encourages the pursuit of further studies in the natural sciences.

1.2 Physics education in Greece

Physics education in Greece follows the traditional teaching model [9]. The most common method is lecturing at all school years with limited experimentation from students. According to a study involving 728 students of the Physics Department of the National and Kapodistrian University of Athens and various National Technical University of Athens departments, 98% had done none or limited systematic experimentation during their school years [10]. Physics student books are obsolete, ignoring discoveries and scientific research done in scientific institutions worldwide [6]. Students without a personal interest in science, somehow grown in them, cannot anticipate covering the gap through school and curricula.

Teaching any subject, but especially Physics requires lifelong learning and continuous specialization. Lifelong learning includes the compulsory stages of education and involves activities in further and higher education as well as continuous learning and education throughout life [11]. Primary school teachers of students 6–12 teach many curriculum subjects, among which is Physics. However, initially, they do not have a specific specialization unless they undergo a Masters' Degree or above, and they lack the expertise to teach out of curriculum Modern Physics and Technology unless they have a personal interest or likeness to be involved [1].

Lack of experimentation in the classroom and lack of everyday connection to Science is also reflected in the ranking of Greece in the PISA competition of OASA [12]. Greece stands below the average of the European ranking (2015). Specifically, the performance in Greek sciences of Greek students is 452 points while the average of OECD countries is 489. Furthermore, it is essential to note a difference in the sexes, with girls showing an improved performance by 11 compared to boys when the average difference in OECD countries is 2 points [12].

In the current paper research, participating female students showed improved performance in STEM labs than male students in their class.

Another study by the University of Athens [6] has shown that teachers, mainly in primary education, have difficulties teaching physics and engineering due to insufficient theoretical knowledge of Physics or general and experimental skills. Also, female teachers have shown more significant difficulties experimenting with electrical and electronic circuits than male teachers from the same study [6].

What is remarkable is that teachers are aware of their shortcomings and actively participate in any training that promotes personal and professional development such as MOOCs (Massive Online Open Courses) and improves knowledge and experimental skills [6]. Continuing professional development is important as the flexible provision of a range of educational opportunities designed to promote lifelong learning [11].

2 The CERN CPD course of "Playing with Protons"

2.1 Physics education at CERN

Since 1998, the European Organization for Nuclear Research has trained middle school science teachers and educators [13]. More than 40 countries participate in the Physics teachers' program, resulting in thousands of students being trained from all countries. Primary school teachers were involved in science training programs only recently. "Hands in the Dough" [14] and "Dans la peau de recherche" [15] are two major primary school science projects in Switzerland and France in collaboration with CERN's big experiments ATLAS and CMS. By 2022, a pioneering installation of experimental activities and an exhibition at CERN premises is expected specifically targeting primary school students, revealing the importance of science in elementary education and even earlier [16].

2.2 The CPD "Playing with Protons" course

The "Playing with Protons" CPD program started at CERN in 2016, providing professional development opportunities to Greek teachers teaching science in the upper primary school [17]. The program was part of the CREATIONS EU project and is supported by LHC experiments at CERN as well as Universities, Institutions, and Research Centers in Greece, UK and Canada. By 2020, 40 Greek primary teachers and 20 primary teachers from the UK have been trained [17]. Since 2016, a total of 155 schools, 346 teachers and approximately 9,000 students in Greece and the UK have taken part in this program.

The "Playing with Protons" program strives for excellence in primary physics education. It aims at helping teachers to try out new physics teaching approaches, especially hands-on activities and experiments, and develop creative lesson plans that build on and enrich their primary curriculum with modern Physics ideas.

In this paper, we present a STEM lab at CERN for Greek primary teachers. The "Playing with Protons – Particle Accelerators and Detectors Lab" has evolved over the years [18] and has been tested by primary school students in Greece [19]. The proposed lab is examined regarding its impact on both teachers' and students' knowledge and skills.

3 Research questions

The question leading this research is whether modern physics and its technological applications can be introduced in primary education. It focuses on hands-on experiments and constructions in electricity and electronics and simple electronics applications that can be taught to K-6 ages.

To design, research, and evaluate our proposal, the following questions were developed.

1. Is it possible to demonstrate with simple everyday materials how the detectors and the Large Hadron Collider work?
2. Can the understanding of the fundamental principles of electrical and electronic circuits be improved through a hands-on lab of physics experiments with simple materials?

These questions are crucial because electricity and electromagnetism are being taught in primary physics education, but not in detail.

4 The "Particle Accelerators and Detectors Lab"

The main goal of the "Particle Accelerators and Detectors Lab" is to transfer a glimpse of the work of physicists and engineers in the research centers for students and push them to seek more knowledge on the subject. Teachers not only learn physics concepts but also start to think like researchers. In this STEM lab, basic electricity and engineering principles were applied to understand the actual experiments and the large-scale engineering at CERN. The lab contributes to understanding both the theory of physics and the actual laboratories through artifacts and models with simple means. The role of the practice laboratories is underlined in all scientific experimental training programs [20]. The lab also developed the skills in teaching different aspects of Electricity and Magnetism.

The "Particle Accelerators and Detectors Lab" is based on the LBD (Learning-By-Doing) methodology. The LBD method is an active learning method suitable for teaching Physics, especially in engineering laboratories [9]. The LBD method was decided for this workshop, keeping in mind that Physics is a research product, and it is essential to be taught as one.

Figure 1 presents LHC prototypes (underground and on-surface) created by K-6 pupils, including correctly wiring the LED circuit.

Fig. 1. LHC models made by K-6 students

Major research centers such as Fermilab [21] and LIGO [22] have developed STEM workshops and seminars with an entirely educational character to make their research understandable and accessible to students and educators.

During the "Particle Accelerators and Detectors Lab," the following questions were to be answered:

- What happens at CERN?
- What does the Large Hadron Collider do?
- How do particle accelerators work?
- How can we study things we cannot even see?

A series of experiments and constructions with simple everyday materials would serve the understanding and skills accomplished. The experiments are basic electrical and electronic circuits that K-6 students may also try. The lab takes place in the classroom. All the experiments can be done in the school lab also, with inexpensive household materials.

The objectives of the lab were to:

1. Understand the basic elements of the particle detectors and accelerator through model construction.
2. Discover the connection between their STEM models and the technology developed at CERN.
3. Realize the use of the fundamental laws of electricity and electromagnetism by experimenting and model designing.

Figure 2 shows an LHC model made by teachers during the "Playing with Protons" lab in 2018 at CERN.

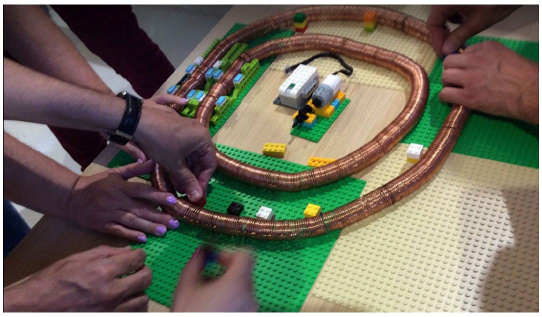

Fig. 2. A collider model made by teachers, "Playing with Protons", CERN

The laboratory was composed of two parts Table 1:

1. Building simple electric and electronic circuits with everyday materials. The purpose was to apply the fundamental principles of electrical and electronic circuits, i.e., Kirchhoff's and Ohm's laws.
2. The design and "reproduction" of LHC accelerator and particle detector models. The purpose was to apply, in this, basic principles of electromagnetism.

Table 1. Shows the "Particle Accelerators and Detectors" lab timeline at CERN [1]

Activity	Time (min)	Method
Simple Experiments	20	Supervised
Individual Work	20	Supervised
LBD Experiments	20	Learning-by-doing
Making LHC Models	50	Learning-by-doing
Whole Group Sharing	10	Learning-by-doing

The "Particle Accelerators and Detectors" hands-on experiments were:

1. Electromagnetic waves emitted by the remote controller (Supervised). The remote control emits infrared electromagnetic radiation, which is detected by the digital camera (Figure 3). The necessity of using detection devices is indicated.

Fig. 3. The remote control emits infrared electromagnetic radiation

1. Study of the collision of two laser beams (Supervised). The difficulty of the collision of the beams in the Large Hadron Collider is being pointed out. Figure 4 shows the collision of the beams with lasers. The experiment aims to understand the incredible technical and engineering achievement of the collision of the beams in the LHC collider at CERN.

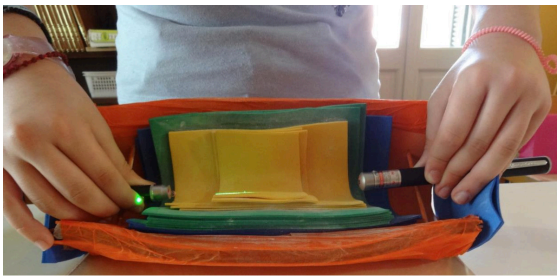

Fig. 4. The collision of the beams by K-6 students

2. Study of Kirchhoff's laws-the creation of electric circuits (LBD). The experiment aims to create simple stimulations of the beams in the LHC. Figure 5 shows the creation of the electronic circuits with LEDs.

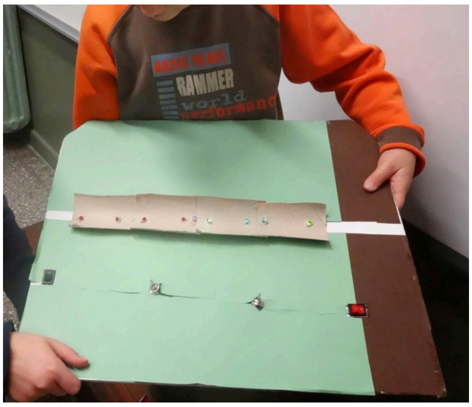

Fig. 5. Simple hands-on electronic circuits

3. Hands-on experiments with coils (LBD). The use of the magnets in the LHC is demonstrated. The magnets make the beams move in a circle.
4. Reproduction of the LHC accelerator and detectors with everyday materials (LBD). The teachers design and build their model of LHC and detectors. The models are based on the experiments performed in the first section of the lab. As a result, the basic elements of the accelerator and its detectors at CERN are "studied" both its terms of construction and function.

5 Methods and results

5.1 Participants

This research was carried out in the fourth year of the CPD course at CERN and the lab "Particle Accelerators and Detectors" has been evaluated from:

- 10 primary physics and IT teachers at CERN in 2019
- 36 K-6 students in 2020 and 44 K-6 students in 2021 in a Greek primary school.

5.2 Evaluation by teachers of the "Particle Accelerators and Detectors" lab at CERN

The results were evaluated based on the participants' responses in relation to:

- the "Particle Accelerators and Detectors lab"
- the evaluation of the program

The recorded responses from the field observations have been also evaluated.

Table 2, below, shows the "Particle Accelerators and Detectors" field observations at CERN.

Table 2. Shows the "Particle Accelerators and Detectors" field observations

Activity	Right	Wrong
Simple Experiments	60%	40%
Electronic devices	50%	50%
Engineering structures	40%	60%
Use of electronics	30%	70%
Making LHC Models	100%	0%
Operation of the LHC	70%	20%

It is shown that that the majority of the teachers did not know how to make simple electrical circuits and use electronic devices and tools. For example, only 40% of the teachers had previous experience in electrical circuit construction.

After the lab, we observed that the teachers understood the basics of electric circuits. They also understood the basic principles of the operation of the LHC and the detectors.

Table 3 shows the "Particle Accelerators and Detectors" results of the worksheets.

Table 3. "Particle Accelerators and Detectors" results of the worksheets

Activity	Right	Wrong
LHC operation	70%	20%
Detection of radiation	40%	40%
Beam collisions	30%	40%
LHC shape	60%	40%
Engineering of LHC	10%	50%

The success is reflected in the feedback we received from teachers during the four years of implementation of the lab. Figure 6, below, presents the teachers' overall rating of the lab quality for 2016–2019.

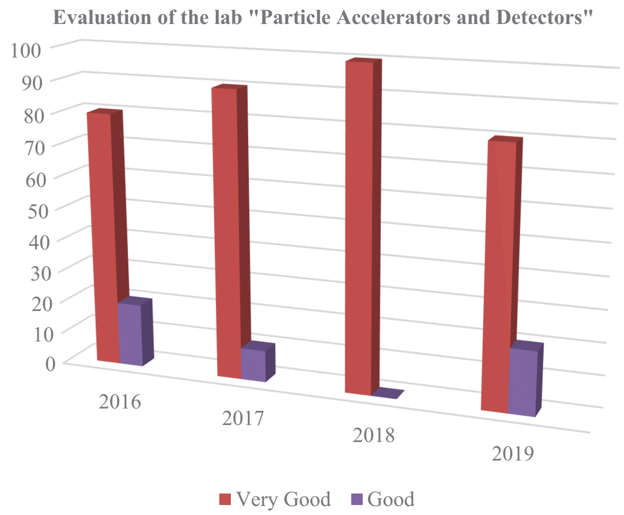

Fig. 6. Anonymous evaluation by primary teachers of the "Particle Accelerators and Detectors" lab at CERN [1]

The second part of the research was performed in 2020 and 2021 in a primary school in Greece with the participation of K-6 students. The results were also evaluated by the responses given on the basic principles of electrical circuits and their applications (before and after the lab)

- on the responses given to questioners
- on the worksheets given for the evaluation of the program

Table 4, below, shows the "Particle Accelerators and Detectors" Lab timeline at school.

Table 4. "Particle Accelerators and Detectors" lab timeline at school

Lesson	Time (min)	Method
Simple Experiments	45	Supervised
Making LHC Models	45	Learning-by-doing
Whole Group Sharing	90	Learning-by-doing
Whole Group Sharing	45	Learning-by-doing

We also evaluated the responses from the field observations and interviews that were recorded during the laboratory.

Figure 7, below, presents the anonymous evaluation for the school lab.

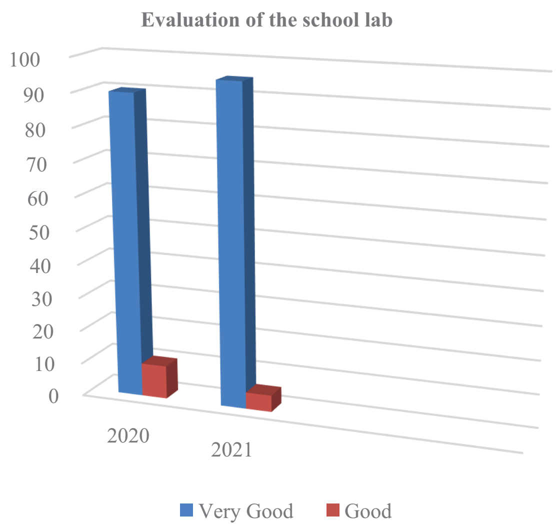

Fig. 7. Anonymous evaluation by students of the "Particle Accelerators and Detectors" lab A

5.3 Statistical analysis

Students were given tests before and after the lab. The tests included the basic theory of electric circuits and experiment-related questions (closed-ended questions, qualitative questions, questions that required experimentation, and questions that differed from what they had encountered in the labs).

Figure 8 shows a sample of the students' tests (questions that required experimentation and questions that differed from what they had encountered in the labs).

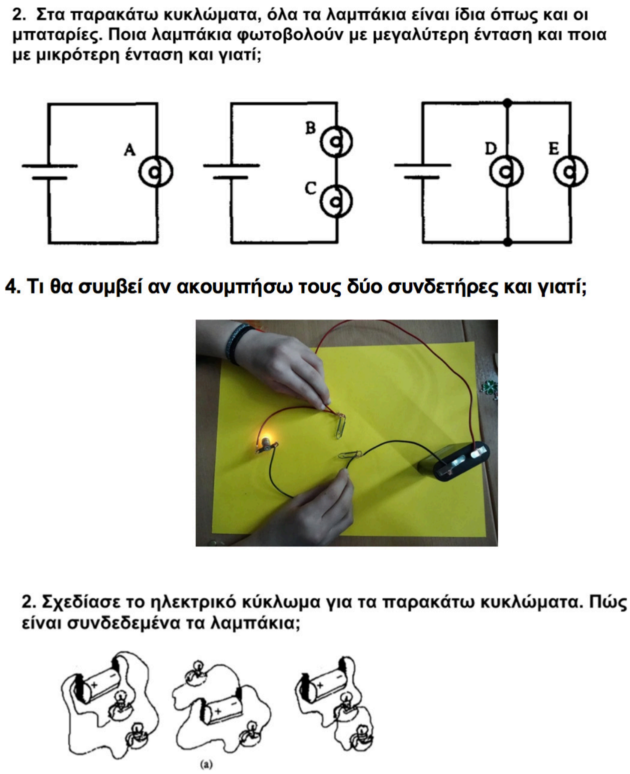

Fig. 8. Sample of students' tests [25]

Table 5 presents the pre and post test results of students participating in "Particle Accelerators and Detectors" Lab implementation at school.

Table 5. "Particle Accelerators and Detectors" lab pre and post test results (2020–2021)

Test Type	N	M	SD
Pre-Test 2020	36	8.92	1.40
Post-Test 2020	36	9.54	1.37
Pre-Test 2021	43	8.64	1.46
Post-Test 2021	43	9.47	0.83

In 2020, all the students (N=36) that took part in the labs completed both pre- and post-tests. Results were graded on a 0 to 10 scale. In addition, a paired-samples t-test was performed to examine variations in students' grades before and after the labs. The results from the pre-test (M=8.92, SD=1.40) and post-test (M=9.54, SD=1.37) showed that the labs improved students' performance and knowledge of physics, $t(35) = -4.235$, $p<0.001$. (Table 5)

In 2021, all the students (N=43) that took part in the labs completed both pre-and post-tests. Results were graded on a 0 to 10 scale. In addition, a paired-samples t-test was performed to examine variations in students' grades before and after the labs. The results from the pre-test (M=8.64, SD=1.46) and post-test (M=9.47, SD=0.83) showed that the labs improved students' performance and knowledge of physics, $t(42) = -6.078$, $p<0.001$. (Table 5)

Statistical analysis occurred by using the IBM SPSS Statistics 26 Program.

6 Discussion

The "Particle Accelerators and Detectors" lab and the proposed innovative pedagogy [3] improved the understanding of Physics laws. Teachers learned how to help students frame and explore their questions, like researchers, thinking out of the box.

Experimental skills of the students have been developed with active learning through hands-on experiments and model construction. Enthusiasm during the lab drives students to experiment with materials and new educational approaches and stimulates students' engagement in physics and technology.

Our research declares that designing and creating LHC accelerator and particle detector models can be an excellent introduction to modern physics and its technological applications.

Additionally, it confirms that student's participation in hands-on workshops is a unique challenge for both teachers and learners. Finally, the suggested method of experimentation can be extended to other thematic units of Modern Physics and technology depending on the scientific interests of each school community.

The field of STEM education has become famous in the current decade. Educators seek training to assign hands-on experiments and activities to their classrooms to improve their students' level of knowledge. Researchers need to propose the most appropriate teaching method so that the STEM laboratory awakens students' interest and leads to particular, measured educational outcomes [23].

7 Conclusion

STEM education research is of great interest because there are no, at least in Greece, modern science laboratories that deal with the latest developments in scientific research.

The authors consider that such research can help introduce Modern Physics to different learners' groups. Creating new science projects at schools, in younger ages with modern and contemporary content, with interactive teaching strategies and advanced teachers' knowledge is what is required in education [24].

More analysis is needed to generalize the outcomes concerning the features of an experimental teaching method in designing and implementing learning environments using simple hands-on experiments in real-world classroom conditions.

Our future research projects concentrate on investigating the effectiveness of various hands-on experiments by implementing cutting-edge alternative pedagogies, which will probably drive to the most efficient combinations to support trainee engagement and enriched learning outcomes.

8 Acknowledgments

The authors would like to thank the CMS collaboration at CERN. The authors would like to thank John Ellis (King's College London), Achille Petrilli (CERN), Mick Storr (CERN), Angelos Alexopoulos, Hector Nistazakis (NKUA) for their support. The authors would, also, like to thank Elena Elliniadou (HUA). The authors are grateful to "Playing with Protons" team, teachers and students.

The authors had the benefit of comments and suggestions by Andromachi Tsirou (CERN).

Any remaining errors and omissions are the sole responsibility of the authors.

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Article submitted 2021-06-12. Resubmitted 2021-06-28. Final acceptance 2021-06-29. Final version published as submitted by the authors.