Using of Distant Education Approaches to Introduce Cutting Edge Science into the Secondary School Classroom

Leonidas Xiros*, Apostolos Tsirigotis, and Antonios Leisos

***Abstract*—The μNet (microNet) project aims to deploy and operate an extensive school network of educational cosmic ray telescopes in Greece. As part of the μNet project, an extended educational program will be conducted, focusing on the construction, testing, and operation of a Cosmic Ray Telescope, as well as the remote operation of cosmic ray detection stations and Astroparticle physics detectors deployed at the Hellenic Open University (HOU) campus. During the 2021–2022 school year, a preparatory phase of the program took place engaging 150 students and 21 science teachers from all over Greece. The high school teachers and students were trained to the experimental procedures of cosmic ray physics using distance learning methods. In this report, we briefly present the methodology we followed, the tools we developed to support the educational program, as well as the findings and results of this preparatory phase.**

***Index Terms*—microNet, remote laboratories, educational cosmic ray telescopes, practical work in school science**

I. Introduction

The predominant belief among science educators is that science education is much more effective with hands on experience than book/classroom learning [1]. Practical work in science provides students with insight into the methods of science and especially into the research practice and experimental methodology [2]. The incorporation of scientific research into schools through pedagogical principles rather than strict scientific formalism is often categorized into three main learning goals [3]: a) learning science, that involves understanding of the theory and its interpretation through mathematical formulas, b) learning about science, that includes the history of science as well as the development of knowledge, and c) learning to do science i.e., engaging in and developing expertise in scientific inquiry and problem solving.

In Greek secondary education which corresponds from grade 7 (students 12–13 years old) to grade 12 (students 17–18 years old), practical work on Physics includes mainly subjects from classical physics, i.e., mechanics, electromagnetism and optics. However, Greek students are also very interested in Astronomy, Astrophysics and Astroparticle Physics which are very exciting and rapidly evolving branches of science [4]. The achievements and advances in these fields fascinate not only students but also the general public since historically the observation of the universe influenced our history, culture, philosophy and religion [5].

The incorporation of these research fields into schools is not an easy task not only from a pedagogical point of view but also for practical reasons including the complexity and the cost of the equipment as well as the advanced scientific methodologies that the high school teachers are not familiar with. It is obvious that recontextualization in modern science should include methods in order that the scientific knowledge and expertise is transferred from academic institutions to high school teachers, who in their turn guide appropriately their students according to the pupils' level of knowledge.

Towards this direction, the Physics Laboratory of the Hellenic Open University (HOU) initiated the μNet project [6], an attempt to engage Greek high school's students to the experimental methodology of Particle and Astroparticle physics. In the μNet framework, students build, test and operate their own telescope in order to observe high energy cosmic rays, mimicking the experimental work of famous scientists during the 20th century that led to great discoveries about the constitutes of matter and the fundamental interactions in the universe [7]. Furthermore, the μNet project aims to the development of a school network of educational cosmic ray telescopes that will be installed in the geographical region of Greece and will be in operation by the end of 2023. The network will act as a scientific collaboration where students will exchange ideas and experiences but also collaborate in order to combine their measurements.

In this work we present the latest developments of the μNet project and the results of the preparatory phase that took place during the 2021–2022 school year, engaging 150 students and 21 science teachers from all over Greece. The paper is organized as follows. In Section II, the main physics aspect of our project is presented, i.e. the study of high energy cosmic rays, and the use of educational cosmic ray telescopes. In Section III, the design features and the evolution of the μNet project is presented, while in Section IV we discuss the tools and methods we have developed during the preparatory phase. In Section V we discuss the main results of the preparatory phase, while in Section VI we summarize our work.

II. Cosmic Rays in Education

In classical Astronomy, astrophysical objects are observed by detecting the emitted light which may be visible (i.e., optical telescopes) or not (i.e. radio astronomy). However, not only light is emitted by such objects; in many interesting cases high energy particles like protons, nuclei and neutrinos[1],

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The authors are with the Hellenic Open University, Patra, Greece.
*Correspondence: xiros.leonidas@ac.eap.gr (L.X.)

[1] Elementary particles that hardly interact making their detection difficult task

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are also produced and propagate through space until they enter the Earth's atmosphere. The detection of these particles using advanced particle detectors along with the corresponding experimental methodologies is usually referred as Astroparticle physics [8], a discipline that actually emerged as a combination of Astrophysics and Particle physics.

A. Cosmic Rays and Atmospheric Particle Showers

These high energy subatomic particles and atomic nuclei that reach the Earth from all directions in the sky are called cosmic rays [9, 10]. The vast majority are protons, but also heaviest nuclei of the periodic table have been recorded to be part of their composition [11]. Cosmic rays are also produced by the Sun but in this case they have smaller energies giving rise to visible well known phenomena in the sky like the aurora borealis (australis). On the other hand, cosmic rays from astrophysical objects within our Galaxy or from other Galaxies have much greater energies but a substantial lower rate [11]. When such an energetic cosmic ray enters the Earth's atmosphere interacts with a nucleus in the atmosphere and produces many new particles (secondary) in cascade interactions, usually called an air shower. The generation and absorption of particles is continuous and as a result a very thin (a few meters) but large disk (the radius can reach hundreds of meters) is formed that is perpendicular to the direction of the initial (primary) cosmic ray moving with the speed light. If the energy of the primary particle is big, the disk can reach the ground level and the particles spread in an area hundred or even thousands of meters in radius. In this case we call the shower Extensive Air Shower (EAS) [12].

Except of these air showers, there is also a continuously flux of muons which are elementary particles like electrons, but much heavier and more penetrative. If we could see these muons they would look like a rain falling on ourselves (i.e. 2 muons per second hit our hand on average). We call this rain, atmospheric muon flux, and it is the result of the large number of low energy air showers that are absorbed inside the Earth atmosphere (i.e. the particle disk does not reach the ground level). The muons that belong to these absorbed air showers survive and can reach easily the ground level or even hundreds or thousands meters below.

B. Educational Cosmic Ray Telescopes

The history of the discovery of cosmic rays is by itself a very interesting topic that shows the evolution of modern physics since many of the particles that are produced in accelerators (i.e., CERN [13]) were initially observed in air showers. However, the interest in cosmic rays is not only historical, they are also of considerable scientific and practical interest, with applications in areas such as archeology [14], in the detection of hazardous cargoes [15], volcanic activity [16], medical applications [17] and many others including the development of networks of educational cosmic ray telescopes.

An educational cosmic ray telescope [18] usually consists of three particle detectors forming a horizontal triangle with a typical distance between detectors of about 10–20 meters. By measuring the relative time that the shower particles pass through the detector units (this information is provided by the particle detectors) and using simple geometry, the direction of the shower axis and consequently of the primary particle can be reconstructed with an accuracy of a few degrees. Furthermore, using the global positioning system (GPS) to provide an absolute time reference, data from distant telescopes can be combined to reconstruct showers originating from ultrahigh energy primaries.

C. μCosmics: the Greek Educational Cosmic Ray Telescope

After the first network of educational cosmic ray telescopes in Alberta of Canada in the nineties, many other similar projects started mainly in USA and Europe. The corresponding project in Greece was started by the Hellenic Open University [18]. By 2014 twelve large (≈1 m^2) particle detectors (Scintillation Detector Modules—SDM) were constructed and tested at the HOU physics laboratory. Even though the SDM proved to be very efficient for cosmic ray research [19], their large dimensions, big mass and large cost made them inappropriate for use in an educational cosmic ray telescope. For that reason, the Physics Laboratory of HOU constructed a low cost (≈3000 Euros), small-scale and portable cosmic ray telescope, the μCosmics detector [20]. The μCosmics detector (Fig. 1) comprises three detector units having 1/6 of the area of the original SDM. The detector unit is very small, easy to carry, weighs about 6 kg and it is much cheaper than the large SDM. The Data Acquisition System consists of a digital pc-based oscilloscope that acquires pulses with a sampling rate of 250 MHz. Simulation studies and experimental data show that the resolution of the μCosmics telescope is about 5 degrees while the recording rate is about 10 showers per hour, which is sufficient even for the short duration of a high school class period.

Fig. 1. The μCosmics telescope (left) with three detection units (white boxes) and the interior of the detection unit (right). Photo taken from reference [20].

III. The microNet Project

As already mentioned, the μNet project aims at the active involvement of high school students in modern experimental methods in Astroparticle physics and especially in Cosmic Rays physics. In the framework of μNet, high school laboratories will be equipped with cosmic ray telescopes, while remote operated detectors deployed at the HOU campus will be available to high school students for distant experimentation [6]. The schools having in situ a μCosmics detector, as well as the schools participating in the distance education activities, will constitute the μNet network, the 1st Greek school network of educational cosmic ray telescopes.

An educational cosmic ray telescope offers the opportunity to introduce students to the physics of Cosmic Rays and to the experimental methodologies and procedures of modern high-energy physics experiments. The simplicity of the μCosmics telescope allows the assembly of the detector units by the students themselves, while the calibration and testing procedures before deploying the telescope, introduce students to modern detector instrumentation. Finally, the operation of the telescope along with the online monitoring of the acquired data, as well as the data analysis, help students to understand the full experimental work and the main physical characteristics of cosmic rays.

According to the educational program, the main task of the students is the construction and calibration of the telescope. However, since most of the time in a year, the telescope will detect showers (i.e. nominal operation) there is a great opportunity for scientific research fostering the citizen science concept [21]. For example, the combination of measurements among distant telescopes will allow the search for time correlated showers that have common origin, a research with great impact on the field.

A. The μNet Activities

The main characteristic of the μCosmics detector is that the students can assemble it by themselves. This is the most important activity because it offers the satisfaction of constructing a scientific instrument. In addition, by interconnecting the components of the detection unit, the students understand the need of each piece as well as the physical processes taking place when particles pass through the detector.

After the assembly of the detector units the students examine the functionality of the telescope. Acting like real scientists they use the atmospheric muon flux in order to test the telescope. The three detection units are stacked on top of each other in order to be penetrated by the same atmospheric muon. On one hand the students realize the existence of the invisible muon flux, while on the other hand they see the electrical signal produced by the detector (response of the detector) when a single particle passes through it.

Using the same experimental setup, the three telescope detection units are synchronized compensating any timing offsets between the detectors. The three electrical signals when the same muon (that moves with the speed of light) penetrates the stacked detector units should appear simultaneously. If not, (i.e. a longer cable results to longer propagation times) proper timing offsets should be applied to the acquired pulses.

These three activities complete the construction and testing of the telescope, which is ready for use. Before detecting extensive air showers, the students can estimate also the characteristics of the atmospheric muon flux. Orienting two detection units to act as a hodoscope (the two detectors are positioned on top of each other with a separation between them of about 1 m) they can determine the angular dependence of the muon flux as well as the rate of atmospheric muons.

In the next activity, students become familiar with the data acquisition (DAQ) system and the online monitoring software. The students use the operational parameters of the detector that they have already measured. They monitor the detection process and the reconstruction of EAS, while by observing histograms they judge about the quality of data and take proper actions. Moreover, by varying the operational parameters they predict and confirm the expected performance of the telescope.

The sixth educational activity is the study of the optimal geometrical layout of the detection units. Using simple spreadsheets, the students can study the effect of the layout on the recording rate and on the reconstruction accuracy of the detected air showers. Even though, the actual layout is a compromise between efficiency and available space for detector deployment, the availability of more geometrical layouts that exist in the HOU campus allows for different selections as well.

Finally, after the 6^{th} activity the telescope starts to operate continuously acquiring data. The students supervise its operation and when the collection of data is over (at the end of the school year) they estimate the detection rate as well as the arrival distribution of air showers and compare with other measurements from other schools and the predictions of the theory.

B. μNet in Action

The first step for the μNet project was a five-day educational program implemented in 2018 and 2019 during two summer schools organized by the Physics Laboratory of HOU. In each summer school, fifteen pupils (The pupils had just completed the first grade of lyceum) from the area of Patras, worked for a week at the HOU physics laboratory. In this first attempt, the comments we received from the students were very positive and the overall picture was very encouraging [22]. The physics of cosmic rays and the concept of particle astronomy fascinated the students. A common misconception among all students that telescopes are only instruments with a lens observing the visible light of distant objects was cleared. It was also very interesting that many students from the Humanities orientation group participated in these summer schools and moreover that we did not notice any difference on their performance in comparison with students form the Science orientation group. On the other hand, pupils with high grades were more confident and more active during their work.

In 2020, a pilot program was applied for the 2020–2021 school term. The pilot project aimed to develop a small school network of educational cosmic ray telescopes in five high schools in the prefecture of Achaia (where HOU is located). Due to COVID-19 we changed our original plan so that the entire training program was conducted by distance. We adapted most of the activities to be done remotely, while teacher and student training took place entirely remotely. According to the evaluation [23], the objectives of the pilot program were achieved to a very high degree. Students felt that they had been adequately trained and that their expectations had been met. On the other hand, the teachers fully supported the project and felt satisfied. They also expressed the belief that remote μNet operations can be exploited by students under the guidance of their teachers, although face-to-face experimentation would be more effective. At the same time, 76% of the students responded positively to the question whether distance education can satisfactorily meet the requirements of such programs.

IV. The microNet Preparatory Phase

Recently, the μNet project got funding by the Hellenic Foundation for Research and Innovation receiving the 1st rank among the proposals in the thematic area "Research & Innovation Hubs in Education". Consequently, it is expected that in 2023 twenty (20) μCosmics telescopes will be installed at high school buildings while more than fifty (50) schools will use remotely the facilities of the HOU Physics Laboratory. The detector construction started in Autumn 2021 and according to the schedule the network will start its activities in October 2022. The μNet educational program, will be offered in the framework of "School Scientific Clubs", that are organized in the Greek Gymnasiums and Lyceums, as complementary to the compulsory education. Students will participate in the μNet activities during weekends or outside school hours in a kind of a school year project starting in October and ending in June.

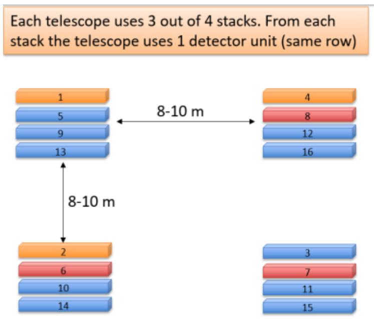
As a preparatory phase of the project, we organized for the school term (2021–2022) a rather small network of schools aiming to the establishment of the experimental educational activities and the development of the necessary educational material. Fifteen (15) schools from all over Greece participated with more than 150 students to this preparatory phase. In three schools the educational program was applied in person, while in the rest the participants attended by distant. The curriculum of the program included the following topics: a) Introduction to Cosmic Ray Physics, b) The History of the discovery of Cosmic Rays, c) The μCosmics telescope, d) Preparation of the telescope, e) Data Acquisition and Online Monitoring and f) Data analysis and results.

The program started on February 2022 and finished in June 2022. During the program several online sessions with all the participants were organized (students, teachers and academic staff) as well as teleconferences only between the school teachers and the academic staff. The online platform used was the WebEx platform, that is used also to the Greek education system and the teachers as well as the students were familiar with. For the schools that had a μCosmics detector in their lab, the presentations were given in person.

For the training of the schoolteachers, regular weekly online meetings were held through the WebEx platform, in order for the teachers to know a priory the student tasks and be better prepared. On their turn, the schoolteachers organized groups of students that participated to the educational activities where each participating school was responsible for one dedicated cosmic ray telescope. In three schools that had in situ a μCosmics telescope the hands on training was performed in situ, while the online training for the remote users was performed by simultaneous experimentation using the μCosmics detectors that were located at the HOU Physics Laboratory and were accessible via the internet. Due to the limited time until the end of the school year only four out of seven activities were included in this preparatory phase. For the remote schools the assembly of the detection unit was replaced by online webcasting of the interior of the unit and relevant e-lectures. The measurement of the muon flux, as well as the coincidence and geometries studies were omitted.

For the educational program, we developed a series of analytical, but short, videos, where the participants could study the underlying physics theory as well as the experimental procedures followed. The students of each school were gathering to their school in order to participate in the teleconferences and also to be guided by their teacher. Each presentation was accompanied by small animations and comprehensive questions that helped the trainees to follow the training procedure avoiding any (written) manuals. After each session there was a game contest where the students of the schools played answering questions. While the students of the schools that had in situ μCosmics detector were playing against each other, for the remote users the schools were competing against each other which proved to be very fun. The tool of the game contest was the kahoot tool [24] and in each game 10 questions were given with four possible answers each. In many sessions except of the online gaming, assessment worksheets were given to the students in order to examine the degree of understanding.

As already mentioned three schools had on their lab a μCosmics telescope. For the other schools (attending by distance), 16 detection units were deployed inside the physics laboratory of HOU. The detection units were arranged in such way (see Fig. 2) that 16 different telescopes each one with three detection units were formed. There were four different geometries, i.e. each geometry was followed by four telescopes. This allowed the comparison of the results between schools that had different telescopes with the same geometry. However, the telescope detection units had slightly different characteristics that made unique the detection and reconstruction rate of the telescopes even if they have the same geometry.



Telescope	Detector Units
1	2,3,4
2	1,3,4
3	1,2,4
4	1,2,3
5	6,7,8
6	5,7,8
7	5,6,8
8	5,6,7
9	10,11,12
10	9,11,12
11	9,10,12
12	9,10,11
13	14,15,16
14	13,15,16
15	13,14,16
16	13,14,15

Fig. 2. The schematic of the detector unit arrangement in the HOU Physics Laboratory. The detectors units that belong to each telescope is also shown.

A. *The μNet-Online Educational Tool*

The main tool of the educational program was a web based application that allowed for the calibration and the operation of the telescopes [2]. The online web application (https://mNet-Online.eap.gr) was divided in two main threads. The first one was responsible for the acquisition of pulses from the four oscilloscopes, while a second one presented the results and performed the analysis on the data.

As it is already mentioned, during the calibration procedure of the telescope the three detection units of the telescope were positioned on top of each other. That way single atmospheric muons could penetrate all three detector units almost simultaneously (atmospheric muons travel almost with the speed of light). The students selected the

[2] The in situ telescopes were operated by the same web application running on the local network

calibration page where either the detector response was determined or the time synchronization of the detector units was performed.

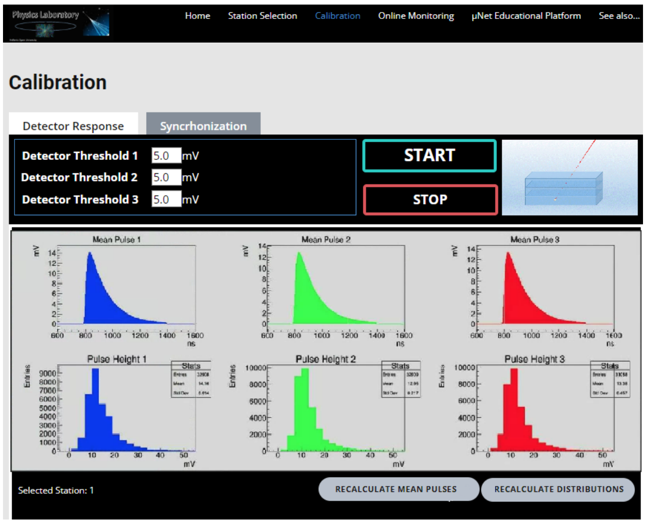


Fig. 3. The Detector Response page where the mean pulses and the three pulse height distributions of a telescope is shown.

For the first case (Fig. 3) after pressing the start button the accumulated pulses were checked in order to examine if three pulses were generated simultaneously indicating that a muon passed through the three detection units. If so, the acquired pulses were processed in order to produce the mean pulse for each device (i.e. show the students the electrical signal that is produced when a particle passes through the device). In addition the pulse peak (the maximum of the pulse) was calculated and a histogram of the peaks for each unit was presented. The histogram showed that the pulses generated by each particle had the same shape but different heights due to the stochastic processes that contribute to the signal generation. It must be emphasized that several presentations and videos were dedicated in order to explain the physics of the signal generation, the stochastic nature of the processes involved as well as the use of histograms and how they are produced.

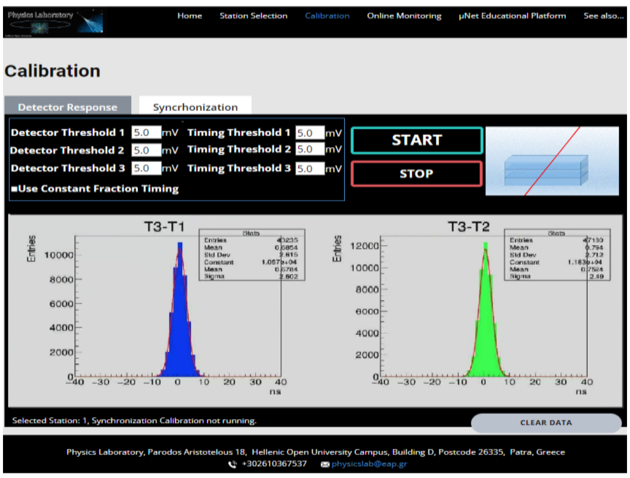


Fig. 4. The Detector Synchronization page where the time differences between two pairs of detectors are shown.

In the same manner the second calibration procedure was about the synchronization of the detector units. When a particle penetrates the detector units simultaneously (i.e., a shower comes directly from above and perpendicular to the ground) the three pulses should appear simultaneously. This is not always case due to the different cables' lengths that produce different delays to the signal propagation. In order to apply the necessary corrections, the acquired pulses when an atmospheric muon penetrated all three detectors were analyzed. The offsets were determined from the distributions of the time differences of the pulses and specifically from the mean values of the histograms (see Fig. 4).

After the calibration procedure, the detection units were positioned as shown in Fig. 2, i.e. they were ready to detect air showers. Each school was monitoring the detection rate and the reconstruction rate of showers, the acquired pulses for each detected shower, along with some other characteristics, i.e., timing of the pulses, peaks of the pulses, etc.

Then the calculated direction of the reconstructed shower was presented in terms of the zenith and azimuth angle and animation of the shower was presented (Fig. 5).

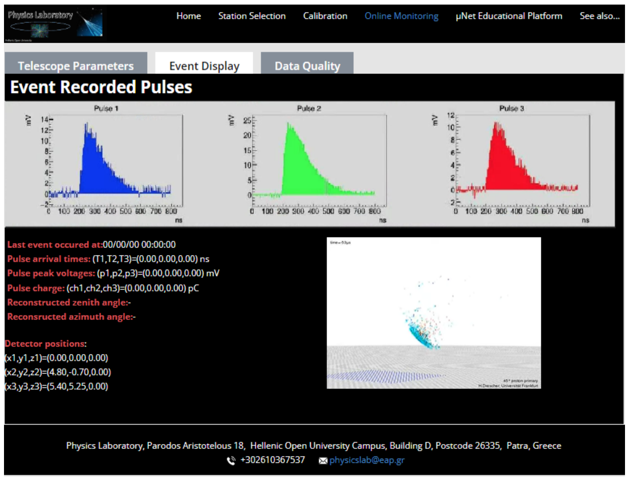


Fig. 5. The pulses of the latest event recorded along with the calculated direction of the shower and an animation of the shower development.

Finally, the last tab of the online monitoring page was used to show histograms that presented the data quality of the telescope. These histograms were also presented on top of corresponding history histograms in order to compare directly the acquired data with data from previous periods of operation (reference period) (Fig. 6)

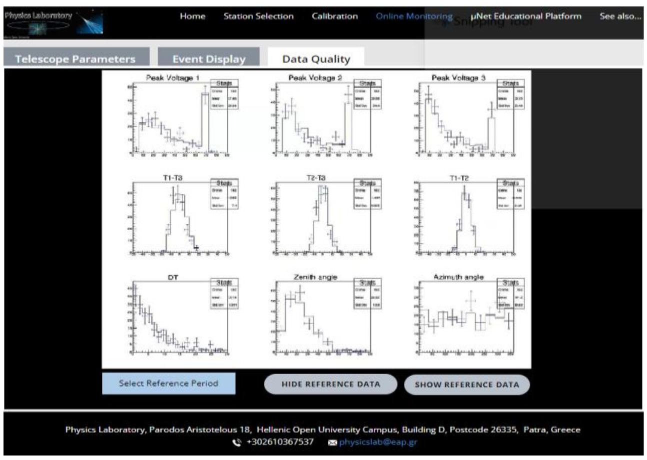


Fig. 6. The histogram page that presents the quality of data of the telescope.

V. Evaluation of the Preparatory Phase

After the completion of the educational program the students of each school prepared a presentation about their work. These presentations along with the game-contest results and questionnaires for the schoolteachers were used to evaluate the preparatory phase.

A. Evaluation of the Acquired Knowledge

The general outcome was that the schoolteachers as well as the students improved substantially their knowledge about cosmic rays. The responses on the degree of knowledge about cosmic rays before and after the educational program are shown in Fig. 7 for both students and teachers.

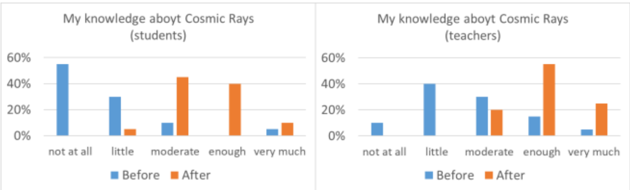


Fig. 7. The responses of the participants about their acquired knowledge

B. Evaluation of Teacher Satisfaction

A large part of the questionnaire was dedicated to the examination of the degree of satisfaction of the schoolteachers. This is very informative since teachers express a need for guidance for the use of material and equipment, as well as on how to support communication with and among students [25]. In this context, the school teachers responded that they exchanged views and interacted with teachers from other schools" as follows: a lot" 20%, "quite a bit" 10%, "moderately" 50%, and "a little bit" 20%. They also believed that the acquired knowledge will be beneficial in their profession with the following percentages: "a lot" 35%, "quite a bit" 45% and "moderately" 20%. To the question if the total time spent on the program was sufficient to achieve the goals, the responses were: "a lot" 25%, "quite a bit" 30%, moderately 35%, and "a little bit" 10%. The responses to the question if the duration of each lesson was sufficient, were: "a lot" 25%, "quite a bit" 50%, "moderately" 20%, and "a little bit" 5%. Finally, the teachers responded positively about their satisfaction concerning the lessons, the adequacy of the trainers as well as the tools and methods used for their training. The results are shown in Fig. 8.

Fig. 8. The teacher satisfaction concerning the lessons, the trainers as well as the tools and methods used for their training.

C. Evaluation of the Online Web Application

Also the main tool of the educational program was evaluated by the teachers. In general, the teachers stated that they were satisfied with the use of the online web application. In particular, the degree of satisfaction is reflected in the following responses: a) the structure of the website was simple and its organization was appropriate: "a lot" 55%, "quite a bit" 35%, "moderately" 10%. b) Navigating in the application was easy: "a lot" 65%, "quite a bit" 30%, "moderately" 5%. c) The images and diagrams were clear: "a lot" 50%, "quite a bit" 30%, "moderately" 20%.

VI. Conclusion

The preparatory phase of the μNet project proved to be very informative for the future application of the anticipated educational program. In this phase 150 students and 21 school teachers participated from 15 schools from all over Greece. The students were trained during weekends by gathering at their school and working as a team under the guidance of their teacher. Educational material based on small videos and presentations, worksheets and online gaming was developed and satisfied the participants who improved their knowledge about cosmic rays. The school teachers were also very satisfied by the tools and methods applied during the educational program and felt confident about the support they received. The online and in situ hands on experimentations were carried out using a web based application that implemented both the calibration procedures as well as the nominal operations of the telescope. The application proved to be very robust and user friendly and will be the main tool of the μNet project for online experimentation.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contributions

L. Xiros conducted the research, analyzed the data and prepared the educational material; A. Tsirigotis constructed the μCosmics telescopes; A. Leisos supervised the educational program operations and wrote the paper; all authors had approved the final version.

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