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Technological semiotic mediators in didactic to approach cosmic rays and improve students' scientific knowledge

I. Veronesi[a,b,*] , C. Aramo[a], R. Colalillo[a,c] , F.S. Tortoriello[b]

[a] *INFN Sezione di Napoli, Napoli, Italy*

[b] *Università di Salerno, Dipartimento di Matematica, Salerno, Italy*

[c] *Università di Napoli "Federico II", Dipartimento di Fisica "Ettore Pancini", Napoli, Italy*

E-mail: iveronesi@unisa.it

This article describes the activities developed in the scientific path of the research project "Mathematical High School" and concerned the analysis of the data detected by the Cosmic Ray Cube (CRC), a muon detector designed in the Gran Sasso (Italy) laboratories. Due to covid-19 the laboratories have been redesigned and calibrated to be developed remotely through e-learning platforms. The didactic impact of the activities will be illustrated in this work. It will describe not only the involvement in the development of fascinating topics not usually carried out in Italian curricula, but also the skills acquired thanks to the development of interdisciplinary themes that highlight how the different fields of the scientific world

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1. Introduction

The “Mathematical High School” research project is an extracurricular educational path dedicated to high school students developed by the Department of Mathematics of the University of Salerno (Italy). In this context, an experimental research-laboratory in the field of astroparticle physics was presented in collaboration with the National Institute of Nuclear Physics (INFN) – Napoli Division (Italy). The laboratory activities concerned the analysis of the data detected by the Cosmic Ray Cube (CRC), a muon detector designed in the INFN Gran Sasso laboratories together with dedicated software for the data acquisition, available also for mobile devices [1], [7]. The pandemic emergency due to covid-19 and the consequent closure of schools with the activation of distance learning, led the researchers and teachers involved in the laboratory activities, to re-elaborate and develop the activities in a convenient format for e-learning platforms. The course also pursued to create a bridge between the worlds of research, universities and schools, to aim at creating the necessary synergies needed to stimulate and to activate participation of students, also with the use of the most recent scientific discoveries.
The research activity described in the article is aimed at the design, implementation and exper that do not require specific spaces for equipped laboratories and that can offer food for thought. Teaching also for non-scientific subjects and in multidisciplinary fields. The aim of this educational path is to actively involve students in situations of knowledge construction and autonomous development of skills, in which new technologies, the design of the teaching activity and the contents are created functionally to involve and motivate students in learning.
The field of investigation also includes the use of technology to support learning objectives and soft skills. Technologies are not neutral and static appendages in teaching, on the contrary they are combined with theoretical assumptions and amplify attitudes and orientations of the cognitive approach [25].
The goal is to identify a new concept of "school laboratory" and to rethink teaching through an active and laboratory approach capable of soliciting students' motivation, curiosity, research method and the use of one cognitive style rather than another, allowing them to build an individual path then mediated with the class group [21].

2.Framework

In Italy, in the National Guidelines, the Ministry of Education underlines the importance of creating interconnections between related knowledge and different disciplines but in curricular teaching developed by subjects, the fragmentation of contents inevitably takes place. The “Mathematical High School” Project is an experimental research project that was created to enhance and develop those interdisciplinary paths that see mathematics as a link between the various fields of knowledge as a bridge between humanistic and scientific culture [22], following up on ministerial requests but also ranging in contents not included in the school curriculum.
The 2010 National Guidelines for the curriculum are the reference text for all schools that replace what was once called "ministerial programs". Schools and teachers use them in their didactic planning activity because they identify knowledge and skills considered indispensable in order to reach the goals for the development of skills.
The objectives are organized into thematic nuclei and provide a reference framework as they underline the need to train people capable of facing contemporary problems within a complex social and cultural system.
In particular, the planning of the didactic path took into account the national indications relating to the scientific field in which the important role of technologies in mathematics for interpreting and understanding natural phenomena is emphasized:
“The computer tools available today offer suitable contexts for representing and manipulating mathematical objects. The teaching of mathematics offers numerous opportunities to become

familiar with these tools and to understand their methodological value. The path, when this proves appropriate, will favour the use of these tools, also in view of their use for data processing in other scientific disciplines. The use of IT tools is an important resource that will be introduced critically, without creating the illusion that it is an automatic means of solving problems. [...]”

And still in another passage of the text:

“The mathematical axis aims to make the student acquire knowledge and skills that place him in the conditions of possessing a correct capacity for judgment and knowing how to orient himself consciously in the different contexts of the contemporary world. Mathematical competence, which does not end in disciplinary knowledge and does not even concern only the operational areas of reference, consists in the ability to identify and apply the procedures that allow you to express and deal with problem situations through formalized languages.

Mathematical competence involves the ability and willingness to use mathematical models of thought (dialectical and algorithmic) and of graphic and symbolic representation (formulas, models, constructs, graphs, maps), the ability to understand and adequately express qualitative and quantitative information, to explore problematic situations, to ask and solve problems, to design and build models of real situations. The purpose of the mathematical axis is the acquisition at the end of the compulsory education of the skills necessary to apply the basic mathematical principles and processes in the daily context of the domestic sphere and at work, as well as to follow and evaluate the logical coherence of one's arguments and others in multiple contexts of cognitive investigation and decision making.”

The didactic choice to develop interdisciplinary didactic activities is also taken up in the analysis of the scientific-technological axis in which the importance of the exploration of the phenomena of nature is evident in order to interpret the world in the broadest sense of the term:

“The scientific-technological axis aims to facilitate the student in the exploration of the surrounding world, to observe the phenomena and understand the value of knowledge of the natural world and that of human activities as an integral part of his global formation. This is a large and important field for the acquisition of methods, concepts, attitudes indispensable for questioning, observing and understanding the world and for dealing with the idea of multiplicity, problematic nature and transformability of reality. [....] The skills of the scientific-technological area, in helping to provide the basis for reading reality, themselves become a tool for the effective exercise of citizenship rights. They help to enhance the student's ability to make conscious and autonomous choices in the multiple contexts, individual and collective, of real life. [….]”

Among the skills that students must acquire according to the National Guidelines, there are those that are enhanced through the activities of the astroparticle path, both the more general ones:

- Analyzing data and interpreting them by developing deductions and reasoning about them also with the aid of graphical representations, consciously using the calculation tools and the potential offered by specific IT applications
- Observe, describe and analyze phenomena belonging to natural and artificial reality and recognize the concepts of system and complexity in its various forms.

And the more specific ones in terms of knowledge:

- Meaning of analysis and organization of numerical data
- Simple schemes to present correlations between the variables of a phenomenon belonging to the scientific field characteristic of the training course
- Identify, with the teacher's guidance, a possible interpretation of the data on the basis of simple models
- Represent data classes using histograms and pie charts.

To conclude this brief examination of the scientific high school curriculum in Italy, we highlight that the 2010 National Guidelines for Scientific High Schools underline the importance of statistics by providing for the development of this theme throughout the five-year period with gradually increasing degrees, instead introduce the study of 3D analytic geometry in the fifth year of the course [24]**.** This issue, addressed at the end of the course of study, can lead to learning problems mainly due to a lack of spatial visualization by students and to the sometimes superficial and hasty development of the synthetic geometry of space [18]. On the other hand, the National Plan for the digital school states that, "digital technologies they intervene to support all dimensions of transversal skills. But they also insert vertically, as part of the literacy of our time e fundamental skills for a full, active and informed citizenship, as anticipated from the Recommendation of the European Parliament and the Council of Europe and as yet best emphasized by frameworks such as 21st Century Skills century), promoted by the "World Economic Forum" [8].

3. Methodology

The methodological approach used for this educational path is constructivist, a learning theory that belongs to Vygotsky in which the construction of knowledge is determined by the interaction with other individuals in a reality that acquires meaning thanks to the active participation of observer [26]. The technologies also allow for levels of involvement and autonomy on the part of students that are decidedly higher than those of traditional teaching, they encourage the development of metacognitive activities, potentially bringing to light more "zones of proximal development". A strong metacognitive framework may really be able to transform students into "scientist apprentices" [9] in an action research [16].
In the design of experimental laboratory courses, first of all, the dynamics of learning to which we want to refer are taken into account and in this regard the activities foreseen in the path presented in this paper are part of a constructivist theory of learning that belongs to Vygotsky and represents the methodological approach that guided the construction of the various experimental paths elaborated by the researchers. The artefacts used, physical or cultural ones, can be the CRC cube with its detectors, the hardware of the instruments and the software for data analysis, or even the physical and mathematical models. They are semiotic mediators of knowledge as they convey the teaching-learning processes guided by researchers and teachers who are invested with the role of cultural mediators [2], [3], [4], [5], [6].
The Covid-19 pandemic has shown in an unassailable way how technology is not neutral nor in everyday life and even less in teaching as human cognitive modalities can be enhanced through the use of artefacts also thanks to cognitive technologies that guarantee communication, manage information and allow to overcome barriers that until recently seemed insurmountable both in terms of quality and quantity of data. Technology affects the mentality of individuals and the dynamics of society by virtue of its strong impact on the mental schemes of those who use it [20]**.** Due to Covid-19, the school underwent a year of distance learning which constantly forced students to learn in front of the computer, so the researchers and teachers involved in the didactic module carefully planned the activities to be carried out both individually and in group through on-line platforms with the aim of developing inclusive teaching, even at a distance, through collaborative learning. In fact, teaching concerns a complex of interventions aimed at designing, managing, evaluating "learning environments", that is, special contexts that favour specific processes in inexperienced students, resulting from the integration of cultural, regulatory and technological processes.
During all the activities, the transversal skills have been consolidated thanks to the peer to peer didactic approach and to cooperative learning [11], thus overcoming the difficulties caused by an incorrect centring of teaching that very often replaces the numerical and visual-spatial domain with the verbal one [17] and overcoming the reluctance towards an area in which one feels less prepared [10]. The skills and competences acquired have led the students to face without difficulty the management and analysis of data relating to Cartesian space [13].
Without neglecting the specific in-depth aspects of the issues addressed, developed during the seminars, conferences and laboratory activities organized by the INFN teachers and researchers,

an attempt was made to focus the didactic action on the learning area closest to the students [27].

4. Data analysis

The activity proposed is based on the detection of cosmic-ray muons. Cosmic rays are particles that come from space, interact with the earth's atmosphere and reach the earth's soil. Studying cosmic rays means taking a look into the deeper Cosmos and observing how the universe is built in its fundamental building blocks [12], [14], [19], [23]. To do this, a portable instrument designed by the Gran Sasso laboratories is used, the Cosmic Ray Cube (CRC) which plays the role of counter and tracker and collect data. The activity carried out with the CRC Cube aims

- To study the trajectories of muons, both to measure their flux at different angles of inclination with respect to the earth's surface
- To reconstruct the trajectory of muons.

The Cosmic Rays Cube (CRC) consists of four layers composed of plastic scintillators.

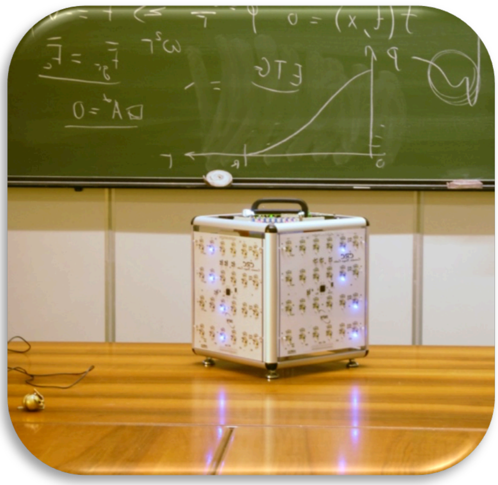

Figure 1: The Cosmic Ray Cube, a counter and a tracker to study cosmic muons. The two faces of the detector are visible. The lit LEDs indicate the muon trajectory.

When a charged particle passes through a scintillator, it produces a light that is collected by a Silicon Photomultiplier (SiPM) and transformed into an electrical impulse that turns on an LED connected to it. The lit LEDs show on the two lateral faces of the telescope the projection of the trajectory of the particles. Students can therefore do a two-dimensional reading of the traces.
To study muon flux, the students counted how many particles passed through the telescope in five minutes, lighting at least one LED per layer. They repeated the procedure by tilting the telescope to different angles, in steps of about 10 degrees [28].
The students

- Imported the data into Excel,
- Did a statistical analysis obtaining the characteristic quantities such as mean, median, mode, deviation, variance,
- Reported data in the Cartesian diagram,
- Chose the distribution that best represented the collected data, i.e. Gaussian distribution.

This first part of the path allowed the students

- To apply the theoretical concerts acquired in statistics in real contexts,
- To acquire fluency in using the electronic spreadsheet to handle a significant number of data,

- To reflect on the scientific, physical and chemical reasons that determined the results achieved.

The second part of the didactic module was dedicated to reconstruction of the muon trace in 2D, thanks to the position of lit LEDs, using the least mean square method. The students learned and then applied the linear regression method for the approximation of data on the Cartesian plane [28]. Since they did not know the theoretical contents of this activity, it was a real learning-by-doing laboratory in which the students learned the contents in a constructive way. Later, also thanks to the use of images and the CRC app that allows a 3D moving view of the detector, they approached the Cartesian geometry in space by observing the trajectories in the Cube, describing the object "point", "line", "plane" in Cartesian three-dimensional space and understanding how to recognize and interpret the intersection between two planes or between plane and line and the reciprocal position between two lines in space.

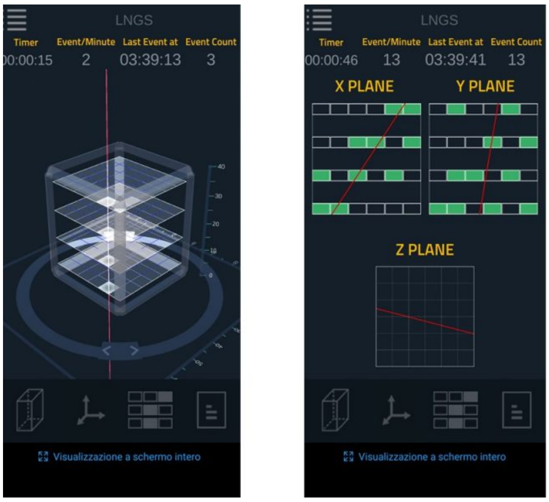

Figure 2: App "*Cosmic Rays Live*"

5.Didactic relapse

Before the beginning of the project activities and at the end of them, students were given a questionnaire with Google forms to fill out online to assess whether the interdisciplinary module of physical mathematics and science on astroparticles had an impact on the learning path of students in terms of acquiring knowledge about covered topics and in terms of understanding the experimental work of the researcher. In-depth analysis of the data emerging from the responses to the questionnaires is described in [4]; below we will briefly outline the salient aspects that emerged.

The first questions were intended to monitor students' knowledge of the work of the physicist, of the objectives of scientific research. Comparing the ex-ante and ex-post questionnaires it was observed that the students at the end of the activities acquired a clearer knowledge of the required topics and understood the purpose of the activities.

In the answers to the questions relating to prospects for future university study, it was observed that at the end of the activities the data are much more dispersed, i.e. there has been a polarization of students between those who imagine university paths similar to research activities and those who do not, even if he expressed his appreciation for the path carried out in the laboratory.

In the last answers emerged that students had a very positive opinion on the expectations related to this course even before starting and this judgment was strengthened at the end of the activities: they found the course engaging, interesting and highly instructive.

In the second part of the questionnaire students had to answer to some open questions for information on the topics of the course about cosmic rays, their speed, their tracks and interactions.

At the beginning of the course, students gave fairly generic answers or none at all, after the activities all the students were able to give correct answers, demonstrating that in addition to having actively participated in all teaching moments despite the limited distance teaching, they understood the contents addressed.

6. Results and conclusions

In the development of the interdisciplinary module of mathematics, physics and science, the students played the role of scientific researchers in the field of astroparticle physics using the CRC detector. Just like "real" scientists, they collected and analyzed data through statistical methods and reconstructed the trajectories of muons with the regression method. To do this they necessarily had to acquire mathematical skills that they did not possess [13], therefore mathematical knowledge has become mediators of the acquisition of more general scientific skills. Despite the development of remote activities due to covid-19, the students maintained high levels of interaction and emotional learning with each other and with teachers and researchers [15]. The didactic impact of the entire course was measured thanks to questionnaires to evaluate the feedback of the design choice.
The students were able to experience in the field how the contemporary scientist and researcher constantly collaborates in research groups using the most advanced technologies, necessarily interfacing with topics that recall numerous disciplines Mathematics Physics Chemistry IT engineering to arrive at results that only teamwork can achieve thanks to the intersections and exchanges of information obtained with powerful technological means. The model of a scientist who, locked in his studio amidst pendulums, stills and telescopes, pursues his research in absolute solitude, has therefore been unhinged from the students' imagination. Indeed, the need to have to work remotely in front of their own computer sharing data and information has shown how the world of research is a "global" world and scientists from all nations can collaborate and share the same project.

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