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Let the instruments speak: Learning physics at the museum

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Summary. — The Physics Museum of the University of Naples is one of the most important physics museums in Italy. With an exhibition of around 900 instruments closely related to the history of the region, the museum is strongly committed to promoting scientific culture. This article describes the numerous activities that the museum offers to all citizens, with a focus on initiatives for school groups.

1. – Introduction

The Physics Museum of the University of Naples Federico II is one of the most important physics museums in Italy. It was founded in 2000 and is housed in the rooms of the former Refectory of the Jesuit Collegio Massimo from 2005 [1]. The large hall of the refectory also houses the magnificent altarpiece of the Circumcision of Jesus, which was originally commissioned by the Jesuit Fathers from the Sienese artist Marco Pino for the Collegio's Church (fig. 1).

The Museum is part of the Museum Centre of Natural and Physical Sciences of the University Federico II since 2012. 900 scientific instruments are on display in an exhibition area of around 640 m^2. These instrumens are related to the development of physics in the Kingdom of Naples and the historical and political events of the city of Naples itself. Most of these instruments date back to the 19th century and come from the Physics Cabinet of the University of Naples, which was founded by King Gioacchino Murat in 1811. The collection originally consisted of optical instruments made by Gennaro de Conciliis, the first director of the cabinet. It was later enriched by instruments from the Nunziatella military school and from the private collection of Abbot Giuseppe Conti.

Under the direction of Gilberto Govi (1878–1889), the Physics Cabinet acquired some fine precision instruments such as the cathetometer, the dividing machine and the Deleuil balance. Later, Emilio Villari, director from 1889 to 1904, added other electromagnetic instruments, some of which were designed by him, such as the quadrant electrometer and the rheometric compass, all of which are still on display today.

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Fig. 1. – The main hall with the altarpiece of the Circumcision of Jesus, by Marco Pino from Siena (1521–1583).

The museum also houses instruments from the Bourbon Royal Collection [2], which were brought to Naples in 1734 after the accession of Charles of Bourbon in the Kingdom of Naples and Sicily. The collection was expanded during the reign of Ferdinand II, who acquired instruments from other European countries.

Seventy-three instruments from this collection were gradually transferred to the University of Naples between 1887 and 1892 and can be seen in the museum today.

The oldest pieces, which form the original core of this collection, date from the 17th and 18th centuries. These unique pieces include: a large objective lens made in Florence by Evangelista Torricelli (1608–1647) and bearing his signature on one edge (his lens is a rare piece, as it is one of the few remnants of Torricelli's production of lenses for telescopes); a magnificent sundial in the shape of a truncated pyramid made of gold and silver; a rare double-burning lens by Brander and Hölscher.

Other instruments in this prestigious collection include the Gambey magnetic compasses, which were used near the Royal Palace of Naples to study fluctuations in the Earth's magnetic field. Also worth mentioning are a microscope presented to King Francis I of Bourbon by the famous optician Giovanni Battista Amici (1786–1863) and a functional model of a locomotive. This model, designed by Robert Stephenson (son of George, known as the "father of railways"), was presented to King Ferdinand II on the occasion of the inauguration of the first Italian railway from Naples to Portici in 1839.

The museum also houses other important instruments designed by Macedonio Melloni (1798–1854) (one of the most important Italian physicists of the 19th century and the first director of the Meteorological and Vesuvius Observatory), such as the double-needle electroscope, his famous optical bench for the study of "radiant heat" (infrared radiation) and the Fresnel lens, which he used during the "VII Congresso degli Scienziati Italiani" in 1845 to demonstrate the radiant power of the moon's rays [3].

The museum's collections are constantly expanding, and still recently some instruments have been acquired, such as the first electromagnetic seismograph by Professor Luigi Palmieri (1807–1896), Melloni's successor as director of the Observatory.

2. – A Museum for all

Recently, the role of science museums has evolved [4]. According to the latest definition of "museums" by the International Council of Museums (ICOM), they research, collect, conserve, interpret, and exhibit tangible and intangible heritage. Museums operate and communicate ethically and professionally, engage communities and provide experiences for education, enjoyment, reflection, and knowledge sharing [5].

In line with ICOM's new mission, the Physics Museum aims to communicate scientific knowledge through preserved heritage and to serve as a tool for dialogue within the community to make science a tangible experience [6].

The Museum enables contact with material objects central to physical knowledge from the mid-18th century to the early 20th century and promotes emotional experiences through historical research, personal stories and insights into the invention and functioning of instruments.

The educational experiences offered by the Museum aim to transmit culture, stimulate curiosity and promote critical thinking in a non-formal learning context [7] and according to the logic of lifelong learning [8].

The Museum is not limited to traditional exhibitions, but also organizes cultural events such as thematic tours, temporary exhibitions, book presentations, workshops and conferences. These events cover scientific, social, ethical and literary topics. The multidisciplinary approach reflects the Museum's commitment to collaborate with various institutions. In addition, the Museum actively contributes to the Third Mission of the University by enriching the public with intellectual growth, critical thinking and the development of conscious and democratic citizens. It plays an important role in the cultural transformation of citizens and the development of the territory [9].

To be inclusive, the Museum collaborates with health authorities and voluntary associations to organize free visits and activities for physically, mentally or economically disadvantaged individuals [10]. In addition, it participates in projects addressing school dropout and illiteracy.

The Museum also participates in various local, national and international events such as "Maggio dei Monumenti", "Futuro Remoto", "La Festa dei Musei", "European Heritage Days" and "European Researchers Night", to name but a few.

3. – The Museum for school

The Physics Museum is mainly visited by school groups, which make up 80% of visitors. To cater to this audience, educational programs have been carefully designed for all school levels. These multidisciplinary programs fit seamlessly into school curricula and use innovative teaching tools to encourage active student engagement. Besides the activities described in the standard "Educational Offer" the museum provides the opportunity to create customized programs in direct collaboration with teachers. These programs aim to delve deeper into specific topics or compensate for the lack of teaching labs in schools.

3˙1. *Guided tours and laboratories.* – Guided tours are the primary form of student engagement with the Museum. These tours go beyond passive observation and immerse students in an "active" exploration led by museum educators where they can interact with historical instruments. Pupils are encouraged to actively observe and reflect during these tours. The collections house a wealth of historical and scientific treasures that provide

fertile ground for interdisciplinary connections. The fascination of standing next to instruments once used by famous scientists provides excitement and successfully engages students, ensuring an effective learning experience.

In addition to the guided tours, the museum offers hands-on lab activities that provide students with an immersive learning experience. Using a combination of didactic apparatus, replica and original historical instruments —such as the Atwood machine, inclined plane, pendulum, optical bench, Fresnel lens, Duboscq telescope, Kirchhoff-Bunsen spectroscope, Wimshurst machine, Coulomb balance, voltaic pile, magnets and simple electrical circuits— students develop skills in measurement, observation and hypothesizing. The "brain-on" method is used in collaborative discussions to derive the basic laws of mechanics, optics and electromagnetism.

The activities are adapted to the level of knowledge of the student groups. For example, to gain a deeper understanding of the teaching methodology used in the laboratory activities of the Museum, let's examine, for instance, the different phases of the mechanics laboratory. The main goal of this lab is to teach students the laws that govern the fall of objects. To determine the students' prior knowledge, a short questionnaire is presented to them via smartphones. This is followed by a phase of historical contextualization in which the students explore the development of scientific thought using Galileo's experiments and writings. In the subsequent discussion phase, the students compare the information presented to them and formulate hypotheses for experimental verification.

The discussion is followed by an actual experimentation phase in which the students carry out the following experiments, three of them with replicas of the original apparatus built as part of previous Museum School projects (Experiments 1 to 3), one experiment with a modern apparatus (Experiment 4) and one with an original apparatus (Experiment 5) selected to ensure the protection of the instrument [11]:

1) Galileo's Chord Theorem: proof of the isochronism of the oscillation of objects dropped along chords of different lengths and inclinations.

2) Pendulum experiments: proof of the dependence of period on length, independent of mass.

3) Experiments with the inclined plane: discovery of the proportional relationship between distance and the square of elapsed time.

4) Inertia experiments: use of a modern inclined plane and a pulley to achieve uniform motion through a balance of forces.

5) Atwood's historical machine: using an original instrument to test the mechanical laws of motion at constant acceleration and to illustrate the different understandings of inertia between Galileo and Newton.

At the end of the lab, the students discuss the experimental observations, compare them with the hypotheses and derive the basic laws for each experiment (fig. 2).

After summarizing what they learned in the Museum with the teachers, the students fill out a questionnaire to evaluate the impact of the activity. The above labs are offered to secondary school students. For preschool and primary school, only the first three experiments are offered with a playful approach. Play is indeed an effective learning tool when children are encouraged to reflect on their observations and understanding in an appropriate debriefing after the activities.

The museum provides all schools the opportunity to carry out laboratory activities with museum educators directly in the classroom, using educational tools and equipment.

3˙2. *Outreach initiatives.* – Notable outreach initiatives for schools include regular seminars run by teachers and researchers. In these seminars, classical physics is explored

Fig. 2. – Two moments of the mechanics laboratory: experiments with inclined plane and Atwood Machine.

in a vivid way and the latest discoveries in modern physics are presented. The Museum's mission is also to guide students towards a scientific university education.

As part of the activities envisaged by the Ministry of Education to develop "orientation paths and transversal skills" [12], the Physics Museum offers two educational projects for schools: Techniques and criteria for setting up a Museum exhibition and Museum operator. The first project provides basic knowledge on the design of "exhibition spaces" that include historical and scientific aspects of scientific instruments. It consists of both a theoretical and a practical part.

The first part covers techniques of exhibition design, instrument care, labeling, cataloging, information collection and exhibit panels preparation. In the second part, students autonomously select the cultural message they wish to convey and the instruments to be exhibited. If necessary for the exhibition, replicas of the instruments are also made, which then remain in the museum and are used for educational activities. Working in groups, they share ideas, interact with peers and tutors and solve problems together to find appropriate solutions [13].

During this training, small museums were set up in schools that had antique physics equipment.

As part of the "museum operator" course, students gain experience in welcoming visitors to the Museum. They are instructed in drawing up a program of visits, selecting instruments for illustration and determining the target audience. The project culminates in the organization of an event in which the students receive groups of visitors and conduct guided tours along the curated path.

4. – Concluding remarks

Since joining the Museum Centre of Natural and Physical Sciences in 2012, the Physics Museum has implemented targeted communication strategies. These aim to promote understanding of scientific knowledge and emphasize the importance of the historical technical and scientific heritage.

The collections have become the focus of educational paths designed to appeal to a wide audience by combining historical narratives and development of scientific thinking with observation of instruments and execution of experiments. Close observation, his-

torical understanding and methods of using historical instruments communicate their original purpose directly and effectively, placing them in the historical and scientific context of the time and thus facilitating their understanding [11].

The technical and scientific heritage is therefore not only the subject of university research, but also serves as a tool for learning physics. In particular, the Museum's close collaboration with schools has shown how an approach to teaching physics based on old instruments, scientific history and active participation promotes emotional engagement and proves particularly effective in achieving students' cognitive goals [14].

The positive results of the Physics Museum's efforts fit seamlessly into the research on learning in non-formal settings and on the educational role of museums. This is evidenced by the growing number of annual visitors and the constant requests for cooperation from local schools. The Museum is thus a place where knowledge about the importance of preserving the technical-scientific heritage and the fundamental role of history and scientific culture underlying the collections is transmitted. This knowledge is crucial to educate informed citizens and strengthen the link with the local territory. In addition, the Museum becomes a valuable resource for teaching physics in schools through the proposed educational activities that are integrated into the classroom.

The Museum staff actively collaborates with teachers and researchers in the field of physics education to gradually develop innovative and effective educational paths adapted to the didactic needs of schools.

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