IL NUOVO CIMENTO **46 C** (2023) 211
DOI 10.1393/ncc/i2023-23211-x

COLLOQUIA: IPER 2022

# School, Museum, University: A community for science education

L. FALOMO BERNARDUZZI(*) and E. M. BERNARDI(**)

*Physics Department and Pavia University History Museum - Pavia, Italy*

received 13 July 2023

**Summary.** — For almost twenty years, the Physics History Group, the University History Museum and the Physics Museum of Pavia University have been elaborating, with schools of all levels, a year-long shared project, leading to the development of strong, long-lasting relationships between the participants and of a community of practice. Within it, new pathways are sought, to allow all participants to live meaningful experiences, to bring school closer to cultural heritage and the local community, and to foster the development of a scientific identity in learners. A methodology including historical-scientific workshops and a focus on Nature of Science was developed. Students are led through educational paths customized according to teachers' requests and produce science stories, which are shared with the community. Because of the pandemic, only upper secondary schools were involved in the last project, Show & Tell. New activities were introduced: a team of students were tasked with online and offline communication, old instruments in schools' collections were put back into use and several final events were organized. Open interviews with teachers highlighted several positive outcomes. Everyone worked alongside, sharing stories, experiences, competencies, intellectual pleasure, codified knowledge and tacit knowledge, in a non-judging environment.

## 1. – Introduction

In the 1980s, the Physics History Group of the Pavia University Physics Department started a series of research activities aimed at deepening the understanding of certain aspects of the history of science, with a focus on its role in science education. These experiences produced results that were the starting point of many educational activities, including the ones described in this article, involving the Pavia University History Museum, the Physics Museum and local schools.

(*) Corresponding author. E-mail: lidia.falomobernarduzzi@unipv.it
(**) E-mail: estermaria.bernardi@unipv.it

 

Fig. 1. – A view of the reconstruction of Volta's Cabinet, with his inventions on the original work table.

Its ancient origins allowed Pavia University to preserve an incredible wealth of objects, books and manuscripts in its museums, libraries and archives. Special attention was therefore placed by the group on the study, digitalization and valorisation of such heritage. Among the primary sources, priority was given to the Physics instrument collections of the Pavia University History Museum and of the Physics Museum, as well as the Physics texts preserved in the historical collections of the University Library and of the Physics Library (today, a section of the Science Library). In 1999, activities also led to the inauguration of the reconstruction of Alessandro Volta's Physics Cabinet (fig. 1) in the Pavia University History Museum [1], on the bicentenary of his invention of the pile. A few years later, the XIX century Physics Cabinet was also unveiled([1]).

From an education standpoint, bringing teachers and learners closer to real scientific practices with a historical approach was believed to be really effective. After all, in the last decades, science history and philosophy have profoundly modified the traditional view of how science developed and what it really means, placing more importance on the subjectivity of the scientists and on the cultural, social, and institutional contexts in which they were and are immersed [2]. Aware that not all the historical intricacies can and have to be covered, the group chose to focus on a certain number of case studies presenting principal conceptual and experimental turning points [3], in a historical framework based

([1]) The group also had an active role in the realisation, in 2005, of the Athenaeum Museum System, which nowadays includes the Pavia University History Museum, the Kosmos Museum, the Pavia Botanical Gardens, the Museum of Electrical Technology, the Archaeology Museum, the Physics Museum, the Chemistry Museum, the Camillo Golgi Museum, the Mineralogy Museum and the collections of Musical instruments (located in Cremona), of Mathematical models, of Anatomy, of Histology and Embryology and Physiology.

on Nature of Science (NoS)([2]).

In agreement with the growing educational literature [5,6], "history" was then transformed into "conceptual stories". "Stories help learners imagine and empathise with the human experience" [7]. The stories were then transformed into digital stories and distributed, together with teaching materials, on websites and wikis first (with 3D reconstruction of instruments and virtual reality environments, as well) and later on the Pavia University History Museum's social media and through an Augmented Reality Application. The AR App, in particular, allows on-site visitors of the Museum to learn more about what interests them and to implement stories that reflect their own point of view or to explore stories made by other visitors and learners [8].

## 2. – Objectives of the projects

Since 2005, the team have fostered an intense collaboration with local schools of all levels [9, 10]; schools were involved in yearly projects titled School+Museum (`https://scuolamuseo.unipv.it/home`) which fall under the "co-creative" category according to the terminology introduced by Nina Simon in museology [11].

The main objective of the projects is to offer a significant experience to the participants([3]).

The experience that we would like for the participant to live within our projects is very similar to that derived by John Dewey and defined by Pugh [12]: "Transformative in that it changes one's relationship with the world. Through an expansion of perception and value, the individual comes to interact with and be in the world differently." (p.110)

These transformative experiences([4]) can be extended, other than to science [14, 15], to the museum field [16] and to a historical approach. From our point of view, they furthermore have to be lived through not just by learners alone, on whom the educational action is usually focused, but by the teachers and by the museum staff, as well.

Developing strong and lasting relationships with teachers from schools of all levels furthermore allows building a community of practice (CoP). It also helps overcome the traditional distinction between formal, non-formal and informal teaching [17]. This community often includes other museums of the Athenaeum Museum System, University Departments and other local realities, such as the Civic School of Art AR.VI.MA. of Pavia and the Astronomical Observatory of Ca' del Monte. The need for integrating

---

([2]) A recent survey [4] on a sample of Italian secondary school Physics teachers confirmed the current relevance of this approach. The survey indeed highlighted how teachers show a positive attitude towards the History of Physics and its use for educational purposes, while doubting their own competence in the matter, given the intrinsic complexity of current history. It also shows the importance for teachers of the historical context and framework in which discoveries took place, as well as the historical development of Physics concepts.

([3]) Involving communities, sharing knowledge and offering visitors "varied experiences": all of these attributes have been included in the current definition of museum, recently issued by ICOM (International Council of Museums). This definition has had a long, complex history and was finally approved in August 2022: *A museum is a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing.*

([4]) For further research, see Pugh *et al.* [13] (2020) as well.

different realities for educational purposes has been highlighted time and time again and has been advocated for by the Ministry of Education and by the Ministry of Culture (previously MiBACT), as well as by many Italian and European institutions and associations [18].

Our co-creative projects aim to connect the world of schools to real life and to the town and to develop a sense of belonging to a community with deep historical roots([5]). This can be done through:

- coming into contact with historical locations where science developed;
- scientific cultural heritage;
- history-science workshops and modern laboratories (the latest "stage" in the making of history);
- representation of science development as human endeavour;
- storytelling, which according to Abrahamson [20] contributes to creating a sense of community and furthermore orients emotions and "appears to be helping learners think critically and understand factual content in a personalised fashion" (p.440).

Moreover, in the final part of the projects, learners come directly into contact with different publics thanks to activities such as exhibitions, meetings, "Stories behind the objects" during which they present their products. Contact with the global community represented by the Internet is achieved through websites and social media.

## 3. – Project phases

**3˙1.** *First phase: settlement and general decisions*. – During the very first meetings, which take place in Autumn, soon after the back to school days, participants agree upon the theme, the specific objectives and the temporal division of the yearly project. Active participation of the teachers is essential: it is the only way to ensure that their needs, motivations and competencies are taken into account and that the separation between formal and non-formal education can be overcome. Active participation furthermore deepens involvement and enthusiasm, which will be passed on to the learners.

In this first phase, a few meetings for teachers' specific professional training on the topic of the project are also arranged.

**3˙2.** *Second phase: fine-tuning, personalization and workshops*. – The starting point of the projects, aside from special occasions (such as anniversaries connected to famous scientists or to the University) that call for some changes, are the instruments or the objects of the University Museums. Sometimes, particularly in the past years, precious

([5]) The idea that museums can play a strong role from an educational standpoint and that they need to have a solid relationship with schools is not, however, a new one. It had already been affirmed in the XVIII century in Pavia and reinforced in the XIX century by Dewey, who insisted on it [19]: "Museums should be an integral part of any educational setting, and the most desirable museums are those that are used for educational purposes and are associated with life activities outside of the museum" (p.419).

instruments from local secondary schools([6]) have become the focus of the activities; they have been carefully cleaned, reassembled and studied, usually by the *PCTO* learners (*Percorsi per le Competenze Trasversali e l'Orientamento* - Pathways for Soft Skills and Orientation, formerly *Alternanza scuola-lavoro* - School-work alternation).

Historical instruments arouse emotions and can be "read" in many ways depending on the cultural background of the onlooker, who can observe them from many different perspectives: the theories behind their operation, the historical period and contexts of use, the effects of their use on society, the attention to detail in their construction or the harmony and beauty of their shapes. Instruments can activate different intelligences [22] and can be explored with different senses, a characteristic which grows in importance as the age of the participants decreases.

The next step is a series of meetings with single teachers or with small groups of teachers from one single school, to define in detail the activities for each class or, in the case of *PCTO* participants, group of learners. From this moment onwards, the activities with the learners can begin, starting with Museum visits and history of science workshops at the Museum and in schools. During the workshops, the Museum staff present relevant historical experiments, making use of easily available materials that substitute substances that can no longer be used for safety reasons; this has the upside of giving everyone the opportunity to replicate the experiments at home, at school or for the general public on special occasions. During the workshops, an inquiry-based approach is used and scientific stories, which bring the participants closer to the human side of scientists and to the contexts of the historical experiments replicated, are narrated. With the older learners, excerpts from primary sources —usually not very used by teachers [4]— also begin to be used [7]. Inquiry-based learning approaches and storytelling, on the other hand, have shown, even in recent surveys, a potential for promoting positive attitudes toward science and science learning, particularly with female learners [23].

**3˙3.** *Third phase: learners re-elaborate and come into contact with the different publics*. – The activities differ therefore not only based on the alignment with school curriculum and interests - as agreed upon during the aforementioned meetings - but also based on the age of participants. After the historical Physics workshops, for children aged 3 to 14 years, the project continues at school with art workshops and also involves other disciplines: for instance, music, informatics and so on. These offers are always strictly connected to scientific activities. Ample use of analogies and images is made, as they stimulate creativity and help learners to reflect on, remember and recount what they lived and learned. Each class comes to the definition of one or more "science stories" and to its telling through different instruments and languages (graphic/pictorial, participative video, podcast, interactive games). The teachers actively participate in all activities and they especially guide their students in the development of stories, with help, when required, by the Museum staff and associates.

Learners of upper secondary school, after Physics workshops, deepen their knowledge of the chosen topics, also aided by their teachers. The historical events narrated at the

([6]) Since the beginning of the 2000s, an operation started with the aim of recovering, studying and attributing value to the instruments of schools in the Lombardy region. The activities involved three schools from Cremona [21], one from Vigevano (Liceo Cairoli) and two from Pavia (Liceo Foscolo —which owns one of the most beautiful collections in all of Italy of Physics instruments from the XVIII and XIX century— and ITIS Cardano). Also in Pavia, Liceo Taramelli and the Pavia Seminary own two small but relevant collections of ancient instruments.

Museum and during the workshops lead the learners towards a research and discovery experience which invests a great number of aspects: cultural, social, economic, political, cognitive, ethical, etc. [2]. Each of them can be a valid object of study, to clarify, with help from teachers of the related subject, the different aspects. For this reason, all the materials related to the topics, prepared during the years and mentioned in the introduction to this article, are made available; this includes primary and secondary sources, multimedia and the AR App (downloadable from the App stores). The learners, under the careful guide of their teachers and with the support of Museum personnel, elaborate their stories, retrace their experiences - sometimes, using historical instruments of their own schools or replicas built by themselves, in case the originals are too old or precious - and train to become explainers during the final exhibitions which collect all the final products developed by the schools. The multimedia stories are also uploaded online.

## 4. – The last concluded project: Show & Tell

The school year 2021-22 was a peculiar one; the first part of the year was still subjected to Covid restrictions, which especially concerned schools with younger learners. The project therefore exceptionally only involved upper secondary schools: *ITIS* "G. Cardano", *LS* "N. Copernico", *IIS* "L. Cossa" and *LS* "Taramelli", which joined four months after the start of the project. 27 teachers (7 Physics teachers, 5 teaching laboratory technicians, 2 Electrical Engineering teachers, 2 Mathematics teachers, 7 Italian teachers, 2 Informatics teachers, 1 Graphic design teacher and 1 English teacher) participated in the project, which followed the phases indicated above and involved 162 students for Physics-related topics and communication activities([7]); 68 of them were PCTO students. The students devoted between 30 and 110 hours to the project; the number of hours differs due to the highly customized schedule and to the specific activities that were agreed upon with the teachers.

As mentioned, for the first time, during this edition, a team of 26 students from Graphic design school IIS Cossa and from the informatics section of *ITIS* Cardano were tasked with online and offline communication.

**4**˙1. *First phase.* – The choice of the main theme and of the communication method for this year's project was influenced by the participation of some learners in the School-Summer 2021 program (*piano Scuola-Estate 2021*), established by the Ministry of Education, which the Museum had joined. On such an occasion, among the different activities offered, learners engaged in the "Stories behind the objects". During this activity, learners showed objects that they held particularly dear, brought from home, and told a story related to them, while the Museum staff narrated hidden stories of the objects of the collections. The Museum objects were shown and left outside of their cases for further exploration. The "Stories behind the objects" were later favourably discussed among some teachers who then suggested the activity during the first meeting of the project. The teachers of the schools involved started searching for ancient instruments that could be used in the project. *ITIS* Cardano houses collections from the XX century, mostly connected to the field of electromagnetism and optics. *IIS* Cossa also found a small

([7]) Additional 46 students were involved in activities pertaining to Medical topics, which are however not the focus of this article.

collection of microscopes while *LS* Copernico, of recent origins, did not own any instrument. *LS* Taramelli has an interesting collection of XIX and XX century instruments; however, having joined the project much later than the other schools, there was no time to study it. Students from both *LS* Taramelli and *LS* Copernico therefore worked on the collections housed at the Museum.

During the following encounters, the topics that the projects would cover were discussed and decided, as well as the objectives of the project and a rough outline of the phases, which could be modified according to the development of the pandemic.

**4˙2.** *Second phase*. – It was agreed to activate two different educational pathways for Physics, one covering electrostatics and electromagnetism and one dedicated to optics. The first focused on some case studies, starting from XVIII century experiments on the electrification of bodies (human bodies, as well), delving on the fundamental step of the Leyden Jar (the first condenser) to arrive at Alessandro Volta's theories and experiments, compared with those by Charles Augustin de Coulomb (the standard model of the time). The interesting debate between Volta and Galvani that led to the invention of the battery was then examined as well. After that, the program continued with the birth of electromagnetism, taking time to analyse theories and experiments by Hans Christian Oersted, André-Marie Ampère (fig. 2), Michael Faraday.

In agreement with the teachers, only parts of the program were chosen for some learners of younger ages. At *ITIS* Cardano, workshops connected with the instruments of the school's collections, carefully cleaned and made available to students under the guidance of the teaching laboratory technicians, were added. As far as optics is concerned, the program began by focusing on the first theories and experiments on the nature of light, to then move on to experimental activities related to geometric optics and colour theory. A researcher from the Physics Education Group of the Physics Department handled this topic.

In-depth analysis was then carried out on microscopy and spectroscopy, leading from microscopes and spectrometers housed in the collections at the schools and at the Museum. For microscopy, in particular, a temporary exhibition was mounted at the Museum, with microscopes from different museums and departments of the University. The exhibition illustrated the evolution of the discipline, from the first simple microscopes to various types of modern optical microscopes and electron microscopes. Different models of microscopes built by exceptional optical instrument maker, astronomer and naturalist Giovanni Battista Amici, whose life and work were studied by a class from *IIS* Cossa, were on display. Learners from *IIS* Cossa also participated in a University microscopy workshop and observed the preparation techniques for tissues used for analysis carried out by optical and electron microscopes. Workshops were organised as indicated in sect. 3.2.

Before or after the workshops from the two programs (optics and electromagnetism) or, for some groups, both before and after, a visit to the Museum was carried out; special attention was paid, during the visit, to topics interested by the project.

**4˙3.** *Third phase*. – The materials necessary to learn more about the topics discussed and to build science stories were supplied online to teachers and learners, at the same time as workshops and visits took place. For physics, materials (primary and secondary sources) and multimedia case studies, mentioned in the introduction, were of great usefulness. For instance, in Volta's case, among the materials offered in digital format were also his *Edizione Nazionale delle Opere e dell'Epistolario* (Scientific Works and Epistolary) [24], including the annotated index which links directly to the different areas where

the topic of interest is covered. This allows enriching the stories narrated with captivating details which can be drawn from some of the very numerous letters written by Volta to colleagues, correspondents dealing with the acquisition of instruments, family members, government officials...

Learners searched for inspiration for their narration not just among the materials made available by the Museum but also online, developing an ability to select meaningful data and for checking its reliability; both are skills that are often underutilised and that are very important for strengthening a critical sensibility and, more generally, a scientific and digital citizenship. For these aspects, communication workshops were of great importance. During these workshops, the theme of digital storytelling (the transposition of the stories built by learners into multimedia formats) was approached, both in a theoretical and practical way. Digital storytelling, as indicated by various research [25-27] and as also observed by ourselves, can contribute to the development of learner engagement while new knowledge and technological skills are being acquired, improve learners' creativity, build a positive classroom environment and develop positive attitudes towards learning. Workshops also dealt with the topic of how stories should be told to arouse empathy and involvement in listening. Not all the learners participating in the project attended these workshops.

Many of the students were helped by their Italian and History teachers while others, belonging to more scientific and technologic curricula, like some of the *ITIS* Cardano learners, referred to more technical approaches; in this case, the perspective was always a historical one. Teachers from *LS* Taramelli however were not as involved in the development of the stories as other teachers, because of the late participation of the school in the project. This confirms the need to involve all institutions since the very early stages of the project.

Stories, sometimes told through digital means, were then listened to by the Museum

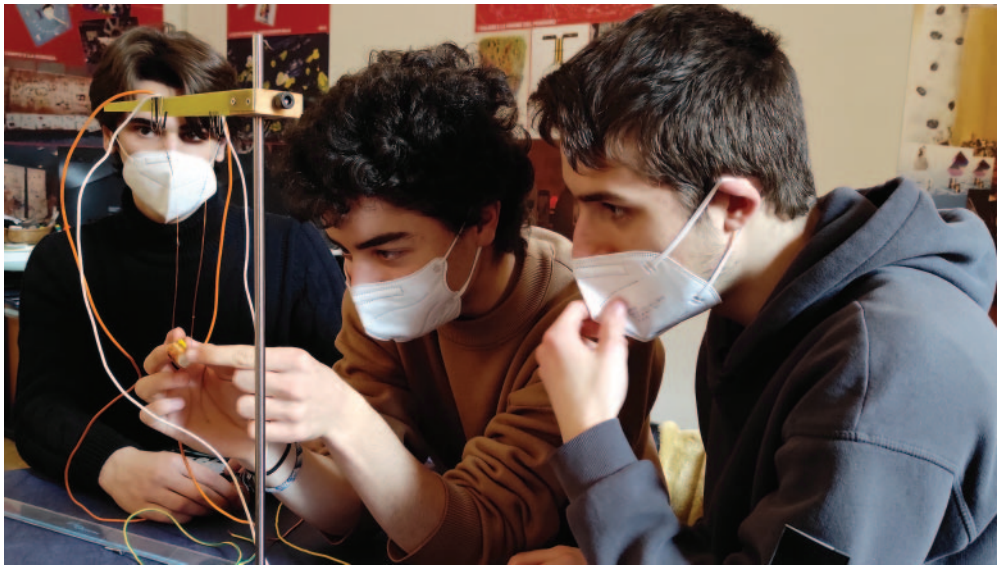

Fig. 2. – Learners from Liceo Taramelli replicate and ponder the exploratory experiments by Ampère.

Fig. 3. – Members of TeamCo (*IIS* Cossa) designing the logo and the mascot (Gregory, a XVIII century frog - a reference to the Volta-Galvani debate).

staff and discussed, and, in some cases, adjustments or integrations were proposed.

At the same time as all other activities and till the end of the project, *PCTO* learners from *IIS* Cossa were assigned to manage the communication activities of the project, under the supervision of their school tutors and of the Museum staff; compared to the other learners, they acquired a very different perspective: they were not only involved in the activities but also tasked with having a global view of the project; their unique position required a special sensibility that embraced all the facets of the project, helping them to distil a stylistic synthesis, fundamental for a consistent and coherent communication. From the choice of colours to the development of a mascot that could represent the program, to editorial products, the learners worked on multiple conceptual levels, translating abstract concepts, such as the historical approach of the project and the strong participative imprint, in concrete products with a strong impact (fig. 3).

The activity of the communication team (TeamCo) also required the participants to interact with the group of learners of *ITIS* Cardano who worked on building the structure of the website dedicated to the project([8]). The two teams cooperated on multiple occasions, recognising the work of the other and coming to shared solutions where the practical rendering of the graphic prototype required substantial modifications. This way of proceeding allowed learners to have a first approach to the type of accommodating and flexible mindset necessary for the work shared between complementary but separate sectors.

([8]) Project website: `http://set.unipv.it/`; social media: `https://www.facebook.com/ShowAndTell.PV`, `https://www.instagram.com/showandtell.pv/`, `https://www.youtube.com/channel/UCVYrylbv7lNAHIaJFnd_MMQ`. Most of the stories told during the final events, plus additional videos produced by the students, are available from the YouTube channel.

Fig. 4. – Electrostatic experiments at *LS* Copernico.


Fig. 5. – Stills from the University event, in the courtyards (learners from *ITIS* Cardano) and in the Main Hall.

At this point, between April and May, direct contact with the public took place. For this edition, instead of the final exhibition, a number of final events were organized. Each school scheduled an event during which the narrations developed by the learners were presented to other classes and, in the case of *LS* Copernico, to future learners and their families (fig. 4).

An event was also organised at the University, in the Main Hall, in the courtyards and at the Museum (fig. 5). During this event, in the Main Hall and at the Museum, learners presented their stories by simply narrating or with the support of digital means (in case of digital storytelling), in the presence of representatives of the Pavia Athenaeum Museum System and of the Physics Department, of the Directors of the schools, of the Director of the Museum, of all other project participants and of the general public. Meanwhile, in the courtyards, historical experiments related to the stories were conducted, involving the different publics as well.

On several occasions, even official ones such as the International Museum Day established by ICOM, learners became explainers at the Museum, learning how to deal with foreign visitors as well. The appreciation was unanimous and great satisfaction was derived by learners.

Contacts between classes, schools and different groups, both during the project and during the events, allowed learners who only dealt with one or few instruments, or maybe of just one case study, to really appreciate the change that occurred in important historical concepts and theories, which happened during a long chronological arc. Special attention was given to this aspect, which, as underlined by other researchers, is believed to be essential in historically informed scientific narratives [28] and is very appreciated by teachers [4].

During the last day of school, a final moment of the project happened in the Main Hall, during which certificates of participation were distributed together with a small parting gift (a bag with the logo of the Show and Tell project, designed by TeamCo). Emotion was, in several moments, well evident, not just for learners but also for the school and Museum personnel, which testifies a strong emotional involvement happened within the project.

## 5. – Final evaluation. Open interviews with the teachers involved

Constant communication and feedback were persistent within the community of practice and between participants; however, after the conclusion of the project, open interviews were carried out with the teachers who had been involved in the project and especially with Physics teachers and teaching laboratory technicians. In their answers, a strong convergence towards positive effects was noticed; this can be summed up as follows.

The project has contributed to:

- expanding the students' point of view on science and its development;
- moving towards a deeper knowledge of the topics chosen, which was especially stimulated by the fact that stories and experiments would have to be presented to several publics;
- improving teamwork skills. Students shared workloads according to their specific abilities and strengths, with the goal of showing the general community what they could produce. In some cases, this has promoted sharing between classes and even between different courses of studies (for instance, between the Applied Sciences High school and the Technical Institute). When an entire classroom was involved in the project, it was noticed how close collaboration between students, teachers and Museum staff to overcome challenges and difficulties encouraged the development of a more serene environment. This aspect was preserved in time and lead to

better student-teacher relationships and less apprehension in seeking help and in exchanging views;

- improving self-esteem. Dealing with different types of public during the final events (at school, mainly with fellow students and family members, and at the Pavia University History Museum —as well as in the prestigious University Main Hall and in the University courtyards— with University students and professors) and the appreciation directed at their work certainly improved the students' self-esteem and their ability to handle anxiety and emotion;
- changing attitudes towards science. Historical and cultural aspects sparked an interest even in students who were typically more focused on humanities and made them curious about science;
- increasing curiosity in researching themes and phenomena, even outside regular curriculum;
- increasing an understanding of the historical and educational value of historical scientific instruments, both at the Museum and at school.

A few other comments also highlight the general appreciation for the project: for instance, several students dedicated to the project more hours than what was required by the PCTO agreement and many students and teachers continued with the new edition of the project in 2022-23. Furthermore, almost all of the fourth year students involved in the 2021-22 edition discussed the project during their high school final exam, as they considered it to be particularly enriching and valuable.

Teachers also highlighted some positive effects on their work:

- experimenting with a different approach to Physics;
- the importance of being able to count on museums and the University as active partners and to be able to discuss experiences with colleagues from other schools;
- the surfacing, sometimes, of unexpected abilities in their students;
- recovering old instrument collections, long forgotten on dusty shelves, which can now be used repeatedly in laboratories for workshops of great interest to the students, whose knowledge and skills they certainly enrich.

The lengthiness of bureaucratic fulfilments and organizational tasks was definitely pointed out as the weak note of the project. Several administrative operations needed to be completed, both from teachers and from the University and museums staff. Moreover, there was a considerable amount of extra day-to-day work for all involved.

## 6. – Conclusions

During the course of the project, teachers, museum and University staff and learners worked alongside, sharing stories, experiences, competencies, considerations, intellectual pleasure, codified knowledge and tacit knowledge([9]), within a community of practice and

([9]) Tacit knowledge [29], a certain amount of which can be acquired by approaching the instruments in a non-linguistic way, is essential in putting the instruments back into action and

in a relaxed, non-judging environment. Learners reported feeling part of the community, a community in which everyone aimed to work not to obtain a good grade but to complete the project in the best way possible. From our perspective, it is of great importance that boys and girls have the opportunity to experience this way of working, which is quite different from the one they are used to, because, instead of trying to adapt to the teachers' requests in order to obtain the desired evaluation, they realise that inside of the group and particularly inside of small workgroups the ideas and abilities of everyone can emerge. As mentioned in the open interviews with the teachers, these aspects are maintained in time and can lead to better student-student and student-teacher relationships and to a more relaxed and less apprehensive school environment.

A desire to get involved is also important, as well as the reinforcement of communication abilities, self-esteem, of a sense of belonging to a community with deep historical roots, of a positive attitude towards science and its learning. The contact with different publics during the events is a fundamental moment for the entire project because it deeply motivates and inspires students.

For all these reasons we argue that the objective of offering the learners a transformative experience was reached.

As for teachers, coming into contact with other schools, with other teachers and with the museum personnel and exchanging points of view contributed somehow to widen their horizons. It contributed to showing the museum in a different light, not just as a location for guided tours or occasional workshops but as an active partner with whom they could conduct experiments and bring learners closer to science, to the local community and especially to the University (which they hope will be a future destination of their learners). During the project, teachers also reported that the activities had, in some cases, changed the way they perceived their learners, as it showed hidden competencies and abilities, maybe even unknown to the learners themselves. Also significant is the fact that this manner of working and the realisation of products and activities which live outside of the schools favoured a detachment from traditional educational methods, which the learners seem to think proposes a program that only has meaning inside of the teaching institution.

The Museum personnel also lived a transformative experience: the objects in the collections were seen in different lights and perspectives, greatly enriching the personal cultural background of each Museum operator; working alongside the learners and the teachers has also modified their way of setting up the visits and, in general, online and offline communication.

* * *

The authors would like to thank all the numerous school teachers involved in the project. *ITIS* Cardano: Cristina Trevaini (former teacher who participated to most of the previous projects and acted as facilitator for all contacts between schools and Museum during this edition), Giuseppe Aromataris, Elisabetta Bucci, Alessandra Calvi, Chiara Cavaliere, Alessandra Citta, Federico Di Palma, Sandro Gallotti, Lorenzo Frontirrè, Filippo Lavecchia, Giada Loprete, Clemente Mazzone, Nicole Messedaglia, Pamela

in repeating historical experiments. It is fundamental from an experimental point of view and it is not easy to acquire. Fortunately, passionate and well prepared teaching laboratory technicians helped operations at *ITIS* Cardano; from them, learners could learn a lot of this type of knowledge.

Morellini, Andrea Negri, Cataldo Pernisco, Giuseppe Pucci, Chiara Zaietta, Erica Zupi Castagno; *LS* Copernico: Federica Archinti, Elisa Municchi, Marta Perotti, Antonio Rovelli, Marinella Zunino; *IIS* Cossa: Rosaria Samarani, Francesco Di Stefano, Matteo Lanzani; *LS* Taramelli: Stefano Sconfietti. We would also like to thank all the University colleagues who very graciously supported the activities: Maria Gabriella Cusella, Maria Carla Garbarino, Massimiliano Malgeri, Federica Riva, as well as Fabio Bevilacqua, former coordinator for the Physics History Group of the Physics Department and initiator of the historical and educational research activities. In particular, we would like to fondly remember Paolo Brenni, who was president of the Scientific Instrument Society at the start of the project. He had kindly agreed to examine the schools' instrument collections and gave indications on how to study and handle them. He sadly passed away during the course of the project. Everyone participated with enthusiasm, sharing their passion and knowledge with the other members of the community.

## REFERENCES

[1] Bellodi G., Bevilacqua F., Bonera G. and Falomo Bernarduzzi L. (Editors), *Gli strumenti di Alessandro Volta. Il Gabinetto di Fisica dell'Università di Pavia* (Hoepli, Milano) 2002.
[2] Matthews M. R., *Science Teaching: The Contribution of History and Philosophy of Science* (Routledge, New York) 2014, https://doi.org/10.4324/9780203123058.
[3] Bevilacqua F. and Falomo Bernarduzzi L., in *Professional Development of Science Teachers: Teaching Science Using Case Studies from the History of Science*, edited by Kokkotas P. and Bevilacqua F. (Amazon-Create Space, Seattle) 2009, pp. 51–80.
[4] Leone M. and Rinaudo M., *Phys. Educ.*, **55** (2020) 035013.
[5] Metz Don *et al.*, *Sci. & Educ.*, **16** (2007) 313.
[6] Klassen S., *Sci. & Educ.*, **18** (2009) 401.
[7] Heering P., *Isis*, **108** (2017) 399.
[8] Falomo Bernarduzzi L., Bernardi E. M., Ferrari A., Garbarino M. C. and Vai A., *Sci. & Educ.*, **30** (2021) 755.
[9] Falomo Bernarduzzi L., Albanesi G. and Bevilacqua F., *Sci. & Educ.*, **23** (2014) 761.
[10] Falomo Bernarduzzi L. and Albanesi G., *Interchange*, **46** (2015) 73.
[11] Simon N., *The Participatory Museum* (Museum 2.0, Santa Cruz, CA) 2010.
[12] Pugh K. J., *Educ. Psychol.*, **46** (2011) 107.
[13] Pugh K., Kriescher D., Cropp S. and Younis M., *Educ. Theory*, **70** (2020) 539.
[14] Pugh K. J., Bergstrom C. M., Heddy B. C. and Krob K. E., *J. Exp. Educ.*, **85** (2017) 629.
[15] Pugh K. J., Bergstrom C. M. and Spencer B., *Sci. Educ.*, **101** (2017) 369.
[16] Soren B. J., *Mus. Manag. Curatorship*, **24** (2009) 233.
[17] Eshach H., *J. Sci. Educ. Technol.*, **16** (2007) 171.
[18] Mangione G. R. J. and De Santis F., *Cult. Digit.*, **0** (2021) 68.
[19] Hein G. E., *Curator: Mus. J.*, **47** (2004) 413.
[20] Abrahamson C. E., *Education*, **118** (1998) 440.
[21] Bellardi A., Falomo L. and Ferrari M. (Editors), *Per dissipare le loro tenebre ed errori ...: strumenti, modi, ragioni della formazione scientifica nelle scuole di Cremona tra età moderna e contemporanea: il Liceo Ginnasio "D. Manin", il Seminario Vescovile, l'Istituto Tecnico "P. Vacchelli"* (Fantigrafica, Cremona) 2009.
[22] Gardner H., *Intelligence Reframed: Multiple Intelligences for the 21st Century* (Basic Books, New York) 1999.
[23] Valle N., Antonenko P., Endara L. *et al.*, *Am. Biol. Teach.*, **83** (2021) 513.

[24] Bevilacqua F., Bonera G. and Falomo L. (Editors), *Alessandro Volta, edizione nazionale delle Opere e dell'Epistolario, Istituto Lombardo Accademia di Scienze e Lettere*, CD-ROM (Hoepli, Milano) 2002.
[25] Nam C. W., *Interact. Learn. Environ.*, **25** (2017) 412.
[26] Dewi N. R., Savitri E. N., Taufiq M. and Khusniati M., *J. Phys.: Conf. Ser.*, **1006** (2018) 012020.
[27] Saritepeci M., *Technol. Knowl. Learn.*, **26** (2021) 193.
[28] Gamito-Marques D., *Isis*, **111** (2020) 582.
[29] Brenni P., in *Historical Scientific Instruments in Contemporary Education*, edited by Cavicchi E. and Heering P. (Brill, Leiden/Boston) 2021, pp. 34–49.