

# Protecting the Past, Shaping the Future. High School Students Test Nanocomposites on Archaeological samples

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**Abstract** – In the last three years our multidisciplinary team of experts from two ENEA laboratories has developed a method to transfer basic skills to high school students, with the aim of fostering their interest in protective treatments for archaeological manufactures preservation. Under guided supervision, young people learn how to apply various materials according to their chemical properties, including nanocomposites, to assess their effectiveness for the conservation of ancient samples, coming from archaeological areas. Students perform tests on the stones before and after treatments to evaluate mechanical and functional properties, hydrophobicity, and adhesion. The hands-on experience provides students with valuable skills in experimental research, materials science, and conservation techniques, whereas the archaeological aspects studied made them more aware of the historical value of their own city and neighbourhood. Feedback collected from the involved classes validates the applied transferring competence method, which can be replicated by other institutions, also to handover different techniques.

## I. INTRODUCTION

The training method, object of this article, has been successfully adopted in the three editions of Pathway for Transversal Skills and Orientation Program (PCTO) aimed at high school students in their fourth year, from both technical institutes and academic high schools.

The two laboratories of ENEA - High Performing Computing lab (TERIN-ICT-HPC) and Micro and Nanostructures for Photonics lab (NUC-TECFIS-MNF) organized PCTO in collaboration with schools with the aim of making instruments and the related research expertise accessible to students, under the supervision of researchers and technicians, who became their tutors for the two days spent in the laboratories located in the ENEA Research Center of Frascati, near Rome, one of

the locations of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

In this way, young people were able to see first-hand how the experts of different scientific fields work directly in the field of chemistry applied to materials for the conservation and restoration of archaeological artifacts .

## II. PCTO PROGRAM ON APPLICATION OF MATERIALS FOR THE PROTECTION OF ARCHAEOLOGICAL ARTIFACTS

The added value of this experience lies in its unique combination of theoretical learning and practical application. In fact, the program begins with an introduction consisting of two short lessons: the first one presents the origin of the materials used as samples mainly fragments of tuff and bricks collected from archaeological site in the southeastern suburbs of Rome, Villa delle Vignacce [1], a Roman suburban villa dating back to the I-II Century AD. This lesson provides also a more general historical and archaeological overview of the urban area, highlighting the broader cultural significance of this lesser-known yet rich-heritage zone of the city. The second lesson focuses on the application of nanotechnologies to the Cultural Heritage field. In particular, innovative protective treatments are discussed, with special attention to the nanomaterials and nanotechnologies that are developed and tested in the laboratory NUC-TECFIS-MNF. Moreover, the lesson provides an overview of the experimental techniques exploited to evaluate their effectiveness in preserving ancient stone materials. Through this introduction, students gain insight into the scientific principles behind conservation technologies and the innovative potential of nanomaterials in cultural heritage preservation.

Afterwards, students will be able to work directly in the laboratory with tools and chemical substances, to apply

the procedure and the treatments on the samples, to perform a series of tests before and after treatment to evaluate mechanical and functional properties, hydrophobicity, and adhesion. Specifically, the wettability of the ancient stones is assessed through contact angle measurements before and after their treatment with the nanocomposites. Through this process, students not only acquire practical skills in conservation science but also develop a deeper awareness of the historical value of their local environment and the importance of preserving it.

The PCTO program was repeated for three years; in table 1 some of the main information about the high school students involved and their activities is summarized.

Table 1. Summary of educational activities conducted with students

Educational Institution	School Year	Course of Study	Number of Participants	Grade Level	Total Training Hours	Training Days at ENEA
Giovanni XXIII – Rome	2022 – 2023	ITIS – Scientific High School I.I.S. –	16	4th year	15	2
Tommaso Salvini – Rome	2023 – 2024	Scientific High School, Material Science ITIS – Technical Institute, Environmental Biotechnology	17	4th year	7	1
Giovanni XXIII – Rome	2024 – 2025	Technical Institute, Environmental Biotechnology	18	4th year	30	2

### III. ARCHEOLOGICAL CONTEXT

The Villa delle Vignacce (Fig. 1), a Roman suburban residence located in the Parco degli Acquadotti (a historic green area in Rome known for its ancient Roman aqueducts), is a significant archaeological site, preserved within the wider Old Appian Way Regional Park.

The Villa, built between AD 125 and 130, is part of a broader archaeological landscape in Rome's southeastern suburbs, rich in ancient and medieval heritage, and is considered one of the most important discoveries in recent decades, due to the use of the incorporation of amphorae within wall construction.



Fig. 1 Villa delle Vignacce: a view of a part of the ruins.

In fact, nowadays traces of amphorae used to lighten the structure can be seen within the fractures of the ruins. This represents one of the earliest dated examples of this construction technique, become quite common in the Roman building later. [2]

The site is interesting also because some excavations conducted between 2006 and 2009 by the American Institute for Roman Culture [3] (in collaboration with the Municipal Superintendency of Rome), revealed numerous luxurious premises, which included bath complex (*terme*) decorated with prestigious sculptures, coloured marbles, and rare glass-paste mosaics, found in excellent condition, but unfortunately reburied soon after documentation.

The site, which had been looted and repurposed over centuries, also yielded evidence of later use during the Gothic Wars in the VI century AD.

Originally, the Villa was owned by Quintus Servilius Pudens, a wealthy brick manufacturer and associate of Emperor Hadrian. Numerous pieces of the bricks (*laterizi*) that used to made up the walls of some rooms into the villa [4], are now scattered around its ruins and for this reason it was possible to use those pieces of bricks as samples for testing activities made by our PCTO students.

Moreover, other spaces of the Villa were closed by walls made by yellow tuff (commonly used by Romans as buildings material). In fact, the students could test the properties, both of tuff and brick coated in different protective materials. Because of these two types of archaeological samples seem both particularly porous and uneven, some pieces of marble *pario* and peperino, already used for previous test in laboratory, were added to be measured, to compare the results with a smoother surface.

Peperino samples were also used as substrates by the students in order to help them understanding real restoring work. In fact, in the framework of regional Project COLLINE [5] led by ENEA researchers, nanocomposites had been already applied on pulpit of the

church 'San Francesco alla Rocca' in Viterbo, that is made by peperino stones (Fig. 2).



Fig. 2 Activities in the framework of COLLINE Project.

#### IV. LABORATORY EXPERIMENT

Laboratory experiments were carried out on blocks of different types of archaeological materials: marble, peperino, tuff and brick (Fig.3). Before applying the conservation products, the students cleaned the different samples by brushing.



Fig. 3 Some coated samples.

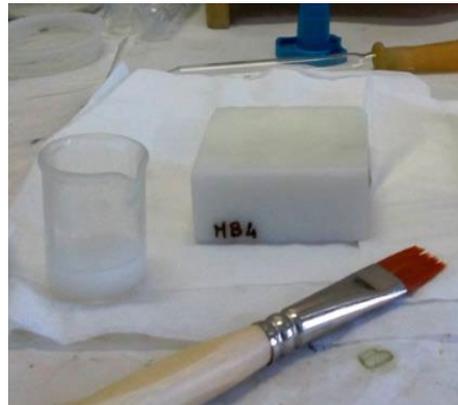


Fig. 4. The phase of application of a protective material on a sample of marble.

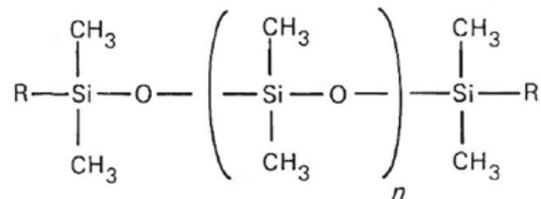


Fig. 5 Rhodorsil RC70 and WR224.



Fig. 6 Set up for contact angle measurements.

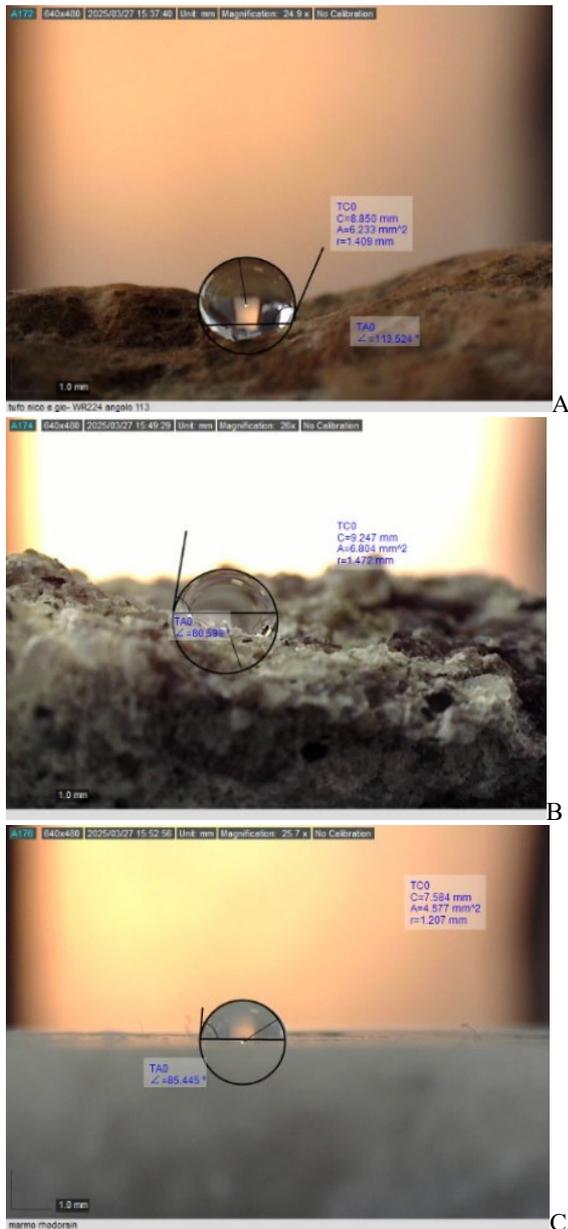


Fig. 7. Zoom on a drop of water on brick (A), tuff (B) and marble (C) with the value of the contact angle.

Therefore, to simulate the treatment in real situation, as performed by a restorer, various protective materials were applied by the students on all the different type of samples, by brushing, until manifest refusal (Fig. 4).

To foster the comparison between different protective materials, three main categories were used:

- Traditional: wax
- Commercial: like siloxane polymers
- Innovative: nanocomposites.

The nanocomposites were obtained by using commercial products as binder and SiO<sub>2</sub> and TiO<sub>2</sub> nanopowders as

mixing fillers. The binders are Rhodorsil RC70 (Fig.5), a polyethsiloxane polymers largely used as consolidant and Rhodorsil WR224, generally used for its hydrophobic properties [6].

For all of these coatings, the students tested the hydrophobic properties measuring the contact angle through a specific in-house setup, consisting of a fibre illuminator that backlights the sample through a diffuser, an adjustable sample holder on which the substrate is placed, and a portable Dino-Lite AM4515ZT digital microscope connected to a computer with the dedicated software DinoCapture 2.0 (Fig. 6) [7]. This setup allows the visualization of the magnified image of a drop of water (Fig.7) gently deposited on the surface of each type of sample and facilitates the measurement of contact angle, to evaluate the local water repellence of the surface coatings.

The more intact the drop remains and the greater the angle between the tangent to the liquid-vapor interface of the water drop and the solid surface, the more hydrophobic the surface is. On the contrary, smaller contact angle indicates greater capacity of the material to absorb water.

During the testing activities, the students had to carefully collect all the data related to the contact angle, which changes depending on the samples and the properties of the protective materials. To be as accurate as possible, they used to take pictures of each measure of the angle observed on the drop of water deposited on the surface of each sample.

Then, they had to analyze the data set to compare, above all, the different effectiveness of the various treatments used to preserve the various ancient materials.

In the last phase of the training the students prepared an oral presentation using slides about the entire experience, to explain, firstly, the goals of their laboratory work and then also the tools and methods applied to reach them. Nevertheless, the crossed comparisons between quantitative and qualitative data, such as ancient material, protective coatings and contact angles revealed much more difficult to show. Therefore, for PCTO future editions we will have to look for a way to improve this more difficult aspect of laboratory activity.

It is also important to highlight that the safe use of nanocomposite materials has been taken into consideration, due to their potential toxicity. In particular, since these materials were handled by students, appropriate protective equipment - such as gloves and lab coats - was required to ensure safe manipulation of the nanocomposites (Fig. 8).

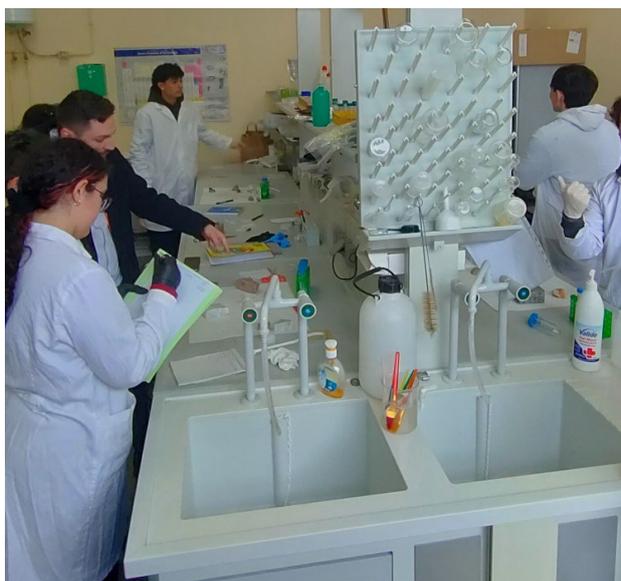


Fig. 8 A group of students at work in the laboratory.

## V. CONCLUSION

At the end of its third edition, the PCTO initiative has allowed us to compare the outcomes of the three editions of the program, make assessments as a whole and deduce a method of transferring scientific skills to groups of high school students. To systematically gather student feedback, we regularly administer an evaluation questionnaire. This approach enables us to continuously refine both the organizational aspects and the educational content of the program, ensuring it aligns more closely with the evolving needs and expectations of the students. Due to this method of collecting and evaluating feedback, in the latest edition of the program, we successfully calibrated the theoretical and practical components, thereby fostering increasingly proactive student participation. Furthermore, based on critical observations from previous editions - where final data presentations made by the students, often shown significant deficiencies, particularly in the logical organization of the collected data and corresponding analyses, as well as in the effective use of tables and graphs to enhance the readability of quantitative findings - we introduced a dedicated one-hour training session. This session is focused on the principles of scientific communication, specifically addressing how to structure an oral presentation and how to show and discuss data in a way that helps interpretation and enables meaningful

comparisons with similar research.

Based on what has been described so far, we can state that we can consider this laboratory-based educational experience to be a successful model, not only due to the effective transmission of archaeological and historical knowledge and application of scientific method, but also because it fosters a welcoming and inclusive environment in which high school students - sometimes unfamiliar with research institutions - felt comfortable and engaged in labs activities. This suggests that the 'learning by doing' approach adopted in our laboratories represents a replicable model for other public and private organizations, interested in disseminating their expertise and promote the use of their research facilities to future generations

In conclusion, our initiatives here described can also play a crucial role in inspiring younger people to pursue careers in scientific research applied for preserving archaeological heritage.

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