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Research Article

Training of Future Chemistry Teachers by a Historical / STEAM Approach Starting from the Visit to an Historical Science Museum

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Abstract. The visit to a scientific historical museum represents a great opportunity for future science teachers to develop educational activities and effective laboratories for high school and first year undergraduate students. In this paper, a pilot educational project experimented in the frame of the course of '*Fundaments and methods of chemistry education*' held at the University of Pisa (Italy) during the academic year 2019-2020, aimed to train future chemistry teachers, is described. The main steps of the project, from the visit to the Museum 'Galileo' in Florence (Italy) to the design of educational hands-on activities by the undergraduate students, are discussed. Emphasis will be given to the role of historical scientific collections, such as the Galilean thermoscopes and other historical thermometers' collection, in stimulating the creativity and higher order thinking skills.

Keywords: High Order Thinking Skills, Education, History of Chemistry, STEM, STEAM, Historical teaching approach, Inquiry-based Learning, hands-on activities.

1. INTRODUCTION

Non-formal learning and teaching are considered important aspects in science education as well as in chemistry education.[1-4] Since the European Community has recognized the role of life-long learning and its impact on the education of aware citizens,[1,2] non-formal contexts started deserving the attention of scientists dealing with education and in particular science education. Among non-formal contexts, science museums[5-8] and scientific festivals, as typical example of contexts hosting open-science and outreach activities,[9-11] were the object of several research studies focusing on their role in increasing the scientific literacy and the engagement of students toward science.[5-13] Several papers, published in the recent years, show that out-of-school programs and outreach activities designed for children, families and/or for school students are effective in terms of acquired knowledges and skills in specific topics about science and technology.[14-18]

Traditional science museums, historical collections linked to high schools or universities and interactive science centres are nowadays strongly connected with schools of any levels, from primary to high schools, and they have developed numerous activities, mainly laboratorial and interactive ones, where science is presented in its relationship with Society and with other disciplines.[5,7,8,18] This approach is an effective alternative to the more traditional and scholastic ways of teaching science through its concepts, laws and more formal aspects. On the other hand, science teachers' training is now focused on a more multidisciplinary and interdisciplinary approach,[18] which is also referred to as the so-called STEM (*Science, Technology, Engineering, and Mathematics*) teaching and learning philosophy.[19] According to this idea, students are encouraged to 'think as a scientist', developing high order thinking skills, such as the ability to solve complex problems by using knowledges and competences typical of different disciplines. In the recent years, this teaching method evolved towards the STEAM approach, which includes 'Arts' to the STEM.[20-23] However, the letter 'A' in the STEAM acronym has a more general meaning: it can be extended to all human disciplines, such as music, history and languages. The basic idea of this teaching and learning method is that a multidisciplinary approach, combining scientific and logical thinking with creativity and multiple intelligences,[21-23] can help students to understand the complexity of the real World and possibly find new solutions to everyday life problems.

This teaching approach has influenced chemistry education, too. The role of human disciplines, such as history and philosophy, as well as the multidisciplinary approach and the use of contextual or situated educational methods[24] to teach chemistry at high school and undergraduate levels can be related to well-known chemistry education models, such the tetrahedral model proposed first by Peter Mahaffy[25] and then structured and reinterpreted by Talanquer[26] and Sjostrom,[27,28] who added relevance dimensions and explained different levels of chemistry understanding and implications in chemistry education.

Within the tetrahedral chemistry education model and its variants,[25-28] teachers are invited to analyse different facets of chemistry education, such as the pedagogical, sociological, ethical, historical and philosophical ones,[29] when working with their students. In line with this model,[25-28] the use of historical approaches to teach chemistry at different school and university levels[30,31] and the introduction of specific courses of 'history of chemistry' and 'chemistry, ethics and society'[32-35] in the curriculum of future chemists represent additional elements of novelty in chemistry education.

Based on these premises, historical science museums and collections of historical objects, such as glassware, scientific instruments, historical books and reactants, as well as ancient artifacts,[6-8,18,30-39] acquire novel roles and values for chemistry teachers who can take advantage of such contexts to teach specific chemical topics and try to engage them with more interactive teaching methods.

In this paper, a pilot educational project[40] experimented upon in the frame of the course of '*Fundaments and methods of chemistry education*' held at the University of Pisa (Italy) during the academic year 2019-2020, and aimed to train future chemistry teachers, is reported.[41,42] The details of the methodology optimized and experimented within this course of chemistry education are reported and discussed in a previous paper.[18] Here, the main steps of the teaching method and the pilot educational project, from the visit to the Museum 'Galileo' in Florence (Italy)[43] to the design of educational laboratorial activities by the undergraduate students, are described and commented on. Emphasis will be given to the role of historical scientific collections, such as the Galilean thermoscopes and other historical thermometers,[44-47] in stimulating the creativity[48] and higher order thinking skills in future chemistry teachers.

2. THE TEACHING METHOD

2.1 The course of Chemistry Education to train future chemistry teachers

The course of '*Fundaments and methods of chemistry education*' of the degree in Chemistry at the University of Pisa[41,42] has been active since 2013 and it is included in the national training program and 'public national competitions' for chemistry teachers to be employed in the secondary schools. As reported in ref. 18, the course is an optional one (3 CFU; total of 24 hours of lessons in the first semester of the third year of the degree course in Chemistry) and it is structured with initial 10-12 hours of lessons aimed to introduce students to the main pedagogical theories and the fundaments of the most used active teaching strategies applied to chemistry education. Emphasis is given on the inquiry-based education and problem-solving methods, different kinds of laboratorial strategies, the basis of the cooperative learning and peer education, and, among the structured knowledge approaches, the 'conceptual maps' method. During these first introductory lessons, students are asked to master these interactive teaching strategies, to read the materials provided during the lessons, through the e-learning platform,[42] to answer some on-going (*in itinere*) interactive quiz and to prepare short presentations. The second part of the course (about 12-14 hours of lessons plus additional extra-hours of activities) is focused on examples of interactive activities aiming to show the best practices in teaching chemistry at intermediate and high schools (from K6 to K12 levels, corresponding to students of the age from 11 to 18 years old). In this second part of the course, a teaching methodology, developed in the last ten years to train future chemistry teachers, called '*STEAM project-based learning*',[18] is applied, as will be discussed in the following paragraph. At the end of the course, students are required to present and discuss a didactic sequence or an educational project, designed and discussed during the second part of the course, in extra-time hours. To prepare the educational activities, students are encouraged to work in group of three-four units according to the cooperative learning method. Moreover, students are invited to follow an instruction scheme, which refers to a hierarchic instructional model,[2,18] which is usually discussed during the progress of the course. Finally, the educational projects designed by students can be put into practice with real school students or with children or families in non-formal contexts, such as science museums, or during open days organized at the *Dipartimento di Chimica e Chimica Industriale*, or they can be presented at Festivals of sciences, such as the one organized in Genova.[9,18,49-52]

2.2 Scheme of the 'STEAM project-based learning' teaching methodology

The scheme of the '*STEAM project-based learning*' methodology[18] adopted within the course to train future chemistry teachers is structured in nine steps:

1) *Visit at the Science Museum*. A visit at a natural or historical science museum, is organized at the beginning of the course in order to get inspiration and to know all key-aspects of a typical non-formal context.

2) *Brain storming and collective discussion*. During the visit, students are stimulated to observe the collections and activities carried out at the museum. Some guided questions are given in order to stimulate students' thinking. Thereafter, a brain storming followed by a collective discussion is performed with the aim of allowing discussion on specific topics related to chemistry to emerge.

3) *Selection of the main topics of the project*. Students usually select few key topics from the previous collective discussion, such as 'mixture among chemical substances', 'the history of the separation techniques', 'colorimetric chemical reactions', 'the chemistry of pigments', and so on. The selected topics are usually strongly related to the museum and to the scientific collections.

4) *Design of the educational activities*. Once the topics have been selected, students start designing the educational activities, which are normally structured following a general hierarchical scheme provided and discussed during the lessons. It is important that the students decide first what the target is (children, families, high school students, …), the context (formal, like a school class, or non-formal, like a laboratory at the science museum) and the main objectives of their educational project. This is the core of the 'STEAM project-based method', where students' knowledges and creativity combine giving rise to the development of higher-order thinking skills.

5) *Preparation of the materials*. The design of the educational activities encourages the students to ask themselves how to put the project into practice, estimate the timing of activities, search for the best materials, such as reagents, bearing in mind safety and environmental issues.

6) *Simulation in class*. When the educational activities are ready, an important step of the methodology is the 'simulation'. This means that students can test their activities during the extra-curricular hours, with their mates, and eventually propose some changes or discuss critical aspects.

7) *Activities with students (at school or at the Museum)*. The most exciting part of the project is the carrying out of the projects with students in a real class or with the more heterogenous attendants of activities in the frame of open days, science festivals of laboratories organized at the science museum.

8) *Analysis of the students' feedback and discussion*. At the end of the educational pathway, students should be able to evaluate their activities, the efficacy of the project and the achievement of the educational objectives. This part of the methodology concerns the meta-cognition level, namely, the developed ability to make self-evaluation and to critically analyse their works. The use of initial and final surveys, as well as the design of specific evaluation tests related to the topics of the project are encouraged.

9) *Conclusion and final report*. At the end, students usually present their work during the final exam or at an event, and discuss all aspects of the project, underlining positive and negative aspects and possible developments. Within this last step of the project, communication skills are also evaluated.

3. THE CONTEXT OF THE SCIENCE MUSEUM AND THE PARTICIPANTS TO THE PROJECT

3.1 Museum of Science 'Galileo'

The non-formal context chosen to put into practice the '*STEAM project-based learning*' method in the academic year 2019-2020, was the Historical Museum of Science 'Galileo' in Florence (Italy).[43]

The Museum 'Galileo' has a long tradition: some of the scientific collections, such as the *Medicean collection* of scientific instruments, were first collected in 1562 by Cosimo I de' Medici (1519-1574), who was the 'Duke' of Florence from the 1537, and then the 'Grand Duke of Tuscany' until his death in 1574. The first location of the historical geographic maps, celestial and terrestrial globes and other scientific objects was Palazzo Vecchio; then they were transferred in Uffizi Gallery, together with other historical scientific instruments. Among them, after the foundation of the '*Accademia del Cimento*' in 1657, inaugurated by Ferdinand II (1610-1670) and Leopoldo de' Medici (1617-1675), the collection was enriched with thermometric, barometric and pneumatic instruments used mainly for research. Additional instruments of mathematics, physics, meteorology and electricity, were added to the scientific collection in the XIX century. Some microscopes, telescopes, micrometers and spectroscopes were specifically built to be hosted in the museum, which became managed by the Institute of the History of Science during the first part of the XX century and finally moved to the actual location, the Palazzo Castellani in the centre of Florence. After 1930, the historic and scientific collections were opened to the public. In the recent decades the Museum 'Galileo' has been largely renovated with the inclusion of didactic interactive expositions and the addition of an increasing number of temporary activities specifically devoted to school students and families.

As it will be discussed in section 4, the Museum 'Galileo' offers several occasions to be in close contact with historically relevant objects and instruments related to chemistry. The famous Table of Affinities (*Tabula Affinitatum*) realized by Franz Huber Hoefer, around the year 1766, is one of the examples of very inspiring historical scientific object conserved at the museum 'Galileo'.[53] This table, in fact, is a first tentative to organize in a systematic way the known elements on the basis of their 'affinities', which are actually connected with elements' chemical reactivity, as reported in ref. 54, and for the analogy with the systematic work done almost one century later by several scientists, as Dimitri Mendeleev, it can be considered a sort of precursor of the Table of Elements. Another example is represented by the historical glassware, containing artifacts such as retorts, alembics, chemical apparatus, eudiometers, precision balances, thermoscopes and thermometers.

3.2 The participants to the project

The education activities here described refer to the academic year 2019-2020, with 23 students attending lessons during the first semester. Among them, 15 students participated in the integrated activities and in almost all steps of the '*STEAM project-based learning*' project, including the visit to the Museum 'Galileo' in Florence, and the design of educational activities for high school students. At the end of the course, 22 of 23 students passed the final exam, with an average grade 28.23 / 30 and their feedback about the project was eccellent.[18] As will be described in the main part of the paper, students attending the 2019-2020 academic year designed their educational activities, stimulated by the visit to the Science Museum, and in particular their focus was the history of thermoscopes and thermometers. This activity was integrated with the usual lessons of the course of '*Fundaments and methods of chemistry education*' and the project was supported by the University of Pisa with a specific didactic project.[40] Unfortunately, due to the covid-19 pandemic, the final part of the project, namely the carrying out of the activities designed by the undergraduate students with real school students, was not carried out in-person.

4. PUTTING THE EDUCATIONAL PROJECT INTO PRACTICE WITH FUTURE CHEMISTRY TEACHERS

4.1 From the visit at the Science Museum…

The first step of the educational project was the visit to the Science Museum 'Galileo' in Florence the 26th of October 2019. The visit was planned in advance with the collaboration of dr. Andrea Gori who is the responsible of the education activities carried out at the science museum. A special guided tour was organized to let students know and enjoy the scientific and historic collections starting from the Medici's and Lorenese collections of historical instruments and maps, and the large collection of instruments of mathematics, physics and astronomy (see Figure 1).[43] The visit to the scientific museum was enriched by an interactive lesson, of about one hour, held in the historical library of the museum (see Figure 1). Here, dr. Andrea Gori talked with undergraduate students about the educational projects and activities typically organized in the science museum, involving children and school students.

Figure 1. Pictures taken during the visit at the Museum 'Galileo' under the guide of the curator of the educational activities at the science museum, dr. Andrea Gori. (photo credit: Valentina Domenici).

Figure 2. Pictures of historical objects present in the Museum 'Galileo' related to Chemistry. On the left: collection of thermoscopes and thermometers designed by Ferdinando II de' Medici in the middle of the XVII century in Florence. On the right: original of the '*Tabula affinitatum*' made by Franz Huber Hoefer in 1766.[56-59] (photo credit: Valentina Domenici).

Students had the opportunity to receive a detailed explanation of the history and scientific relevance of the objects and instruments hosted in the room dedicated to '*Chemistry and the Public Usefulness of Science*' and of the glassware collection in '*The Accademia del Cimento: Art and Experimental Science*' room (see Figure 2).[53,55-57]

Before visiting the museum, students received an 'observation guided template' with some guided questions aimed at giving them some non-formal instructions on how to better observe the collections and to visit the museum with a critical attitude (see Table 1). Moreover, students were invited to prepare some questions concerning the laboratorial activities designed for students and for children by the museum 'Galileo'. Thanks to the competence and availability of the curator, dr. Andrea Gori, students could have a concrete idea how laboratorial activities for school students are designed and performed in a science museum.

After the visit to the museum, a lesson was dedicated to a collective discussion (step 2 of the project) concerning the experience at the science museum and an interactive activity was organized to put together students' impressions and observations during the guided tour. Some posters were prepared hosting their answers to the questions reported in Table 1 and other comments made by students (see some details of the posters in Figure 3).

Step 3 of the '*STEAM project-based learning*' methodology, namely the selection of chemistry-related top-

Table 1. 'Guided questions' given to the students before visiting the Museum.

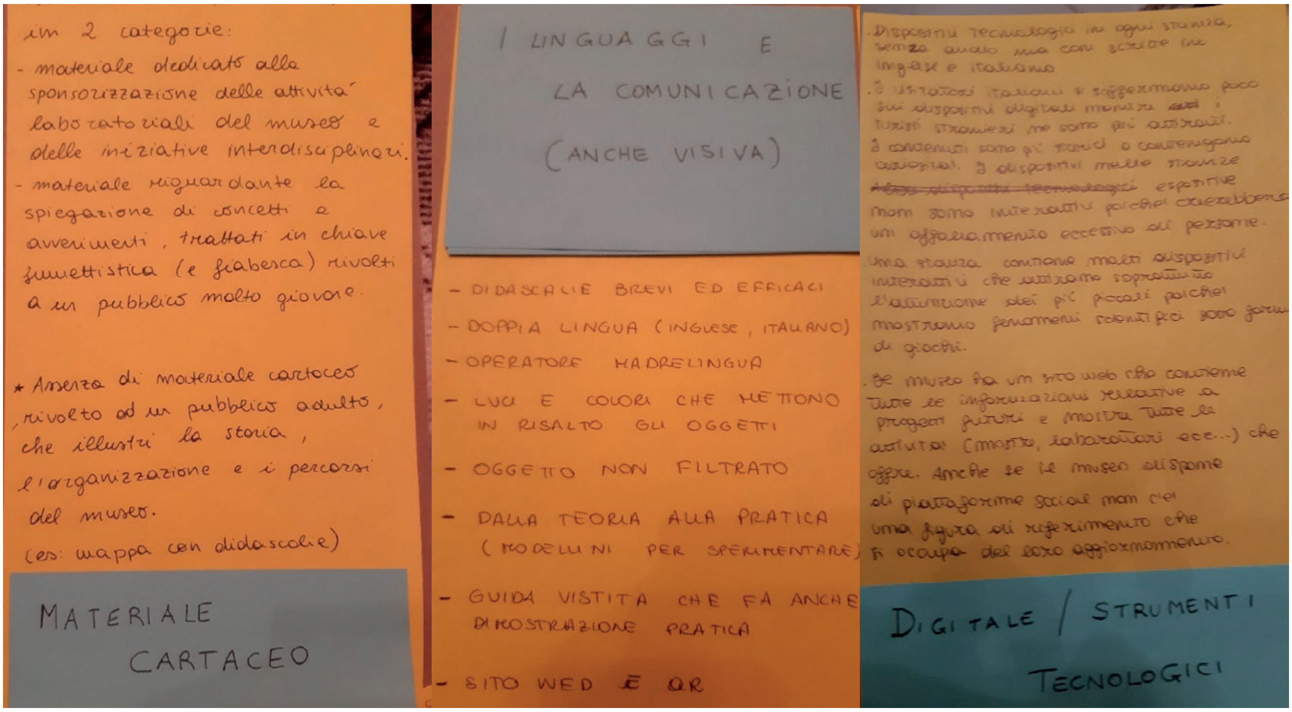
Observe the 'texts'	Are there written captions close to the scientific objects? Are there texts in different languages? How long are the captions? Do you think they contain all important information? How big and readable are the texts? Other comments…
Observe the 'collections'	What is the criterion of exposition? How are the expositions and the collections organized? Describe how the museum is structured and choose a room as an example. How are the scientific instruments and historical objects exhibited?
Observe the 'digital and media tools'	Are there digital tools in the museum? What are they like? Are there video projections? Are they used by the visitors? Describe one of these tools.
Observe the 'didactic laboratory' and 'educational activity' room	Is there a room or a space dedicated to the laboratorial activities with school students? How are the permanent exhibits specific for school students and children organized? Find all details about the planning and design of activities and ask to the guide relevant information, such as: how many students visit the museum every year? What is the main target? Are the laboratorial activities related to some specific objects or instruments present in the collection? What are the typical approaches used during the laboratorial activities? …
Observe the 'catalogues'	Examine the catalogues. Are there in print and / or digital ones? Are there informative materials for children? What is the language used? Are there photographs or pictures in the catalogue? Are the catalogues complete/ non complete / …? Are there brochures, posters and so on?
Observe the 'accessibility' of the Museum	Comment on the accessibility of the Museum to people with different disabilities. Do you think that all people can easily access to the museum? What are the limitations, if any?

ics inspired by the visit to the science museum, was an interesting part of the students' work. Students were very impressed by some historical objects, such as the Antonio Santucci's Armillary Sphere[60] and other mathematical instruments, and as a first activity, they tried to make some analogies between these historical models of the Universe and the models of the Atom developed at the end of the XIX and beginning of the XX centuries. Despite of the stimulating discussions, students moved their focus on 'more-chemical' objects, such as the '*Tabula affinitatum*' and the glassware collections of the museum 'Galileo'. At the end of this collective work, students decided to choose the historical thermoscopes and thermometers[59] for their further activities. Among them, it is worth noticing some particular thermoscopes, such as the *cluster thermometer*, consisting of six phials clustered on a column and resting on a round pedestal. Each phial contains a small glass sphere having a different density: density is the physical property at the basis of the motion of these spheres in the six phials when temperature changes. A series of *fifty-degree thermometers* with coloured liquids and a set of *thermometers with snail stems* also attracted the undergraduate students. As most of the thermometers collected at the Museum 'Galileo', the invention of these thermometers is attributed to Grand Duke Ferdinand II de' Medici and they were used by the members of the *Accademia del Cimento* mainly for meteorological applications. In addition, the historic collection at the museum 'Galileo' contains several thermoscopes, as the so-called 'Galilei's thermoscope, which was invented by Galileo during his stay in Padua in 1597.[61] These thermoscopes and thermometers were the object of educational activities devised by students, as will be described in the following paragraphs.

4.2 … to the design of the educational activities

The step 4 of the project is the design of educational activities to be carried out at school (formal context) or at the science museum or during open days at the University (non-formal context). Undergraduate students who participated to the visit to the museum 'Galileo' in Florence were divided in three groups of five students; then each group started working on some sub-topics related to the more general theme of '*Thermoscopes and the thermometers*'. Students decided to focus on the history of the thermoscopes and thermometers present in the science museum 'Galileo', such as the history of the discovery of the thermoscope by Galileo Galilei. One group decided to design a laboratorial activity concerning the construction of a thermoscope and the calibration of a thermometer. All activities were planned for high school students following a general hierarchic scheme of educational instruction (see Table 3 in ref. 18). Some educational aspects of the activities are reported in Scheme 1 for the three projects designed and proposed by the undergraduate students and in Figure 4 some photographs and drafts of the thermometers and thermoscopes object of investigation by the students during their educational project are reported.

During this activity (step 4 of the project), undergraduate students were very much interested in the sto-



(a) (b) (c)

Figure 3. Observations and comments made by the students during the visit at the Science Museum concerning several aspects as indicated in Table 1: comments about (a) the presence of catalogue, captions and brochures; (b) the language used, the type of communication, the presence of a web-site, eventual videos and animations; (c) the presence of interactive and digital tools, educational exhibits.

ries around the attribution to Galileo Galilei of the discovery of thermoscopes and thermometers. In fact, they knew about the Galileo's thermometer, which was not actually discovered by him, and they didn't know about the Galilei's thermoscope. This last one, as that reported in Figure 4a, was invented by Galileo Galilei to measure temperature when he was professor in Padua in 1597.[61]

This thermoscope consists of a small ampule with a long neck. The ampule is heated by the hands and then it is reversed and partially immersed in a container filled with water. When the hands are removed, the air in the ampule becomes colder and contracts, so that the water rises in the neck. The changes in air density due to the change of temperature are easily visualized by the increase or decrease of the level of water in the neck. It seems that the first liquid used by Galileo was the spirit of wine and later still the Grand Duke Ferdinand II of Florence, a former pupil of Galileo, used coloured spirit of wine and reduced the dimension of the tube to get a more precise instrument.

The so-called Galilei thermometer, as that shown in Figure 4b, was actually invented by members of the '*Accademia del Cimento*' in Florence, between 1657 and 1667, and for this reason is also called 'Florentine thermometer'.[46,47] It consists of a sealed glass cylinder containing a transparent liquid with suspended small glass spheres, called floaters, containing a coloured liquid. Each floater contains a liquid with a slightly different density, associated to a temperature tag. The principle of working is based on the temperature-dependence of the density of liquids. The liquid in the cylinder is in contact with the external air through the glass and it is supposed to be in thermal equilibrium. When the temperature increases the liquid in the cylinder decreases its density due to volume expansion, and floaters containing a liquid with lower density start moving up, while floaters with higher density go down. The temperature of the liquid of the cylinder is something in between the two floaters closer to the centre of the cylinder (such as the green and yellow floaters in Figure 4b).

During steps 5 and 6 of the project, which are focused on the preparation of materials and the simulation of the designed activities, undergraduate students were very much interested in the historical part. For instance, they realized that the motivation at the basis of the invention of the thermoscopes and thermometers, mainly related to meteorology (i.e. knowing the air temperature, and the changes during the day or during a

Scheme 1. Main aspects of the three educational projects designed by the undergraduate students who visited the science museum 'Galileo' in Florence.

Relevant aspects	Description
	Activity n. 1 (first group of students)
Scientific topics	The thermoscopes. History of the thermoscopes of the scientific collection at the museum 'Galileo'
Target	High school students (first year)
Main chemical-related topics	Glassware, liquid and gas states of matter, expansion of gases and liquids and temperature effect, density of liquids, temperature.
Guided questions / inspiring questions to start the activity	What is a thermoscope and what is its use? Who invented the first thermoscopes? Look at these objects (real ones or photographs, as the ones reported in **Figure 4a**) and search for information about their history, inventors, functioning (guided activities on the web).
Methodology	Inquiry-based activities; historical approach.
Timing	2 hours
Notes	This activity is particularly useful to introduce the topic of 'temperature' and how different chemical substances behave by changing the temperature, and how liquids and gases behave at different temperatures.
Main educational objectives	Search for information about the history of an instrument by using materials provided by the teacher and on the web. Understand the principles of functioning of a 'thermoscope'. Understand the phenomenon of gas expansion by changing the temperature. Understand the role of the shape of glass components of a thermoscope. Know the role of the first thermoscopes and their first applications.
	Activity n. 2 (second group of students)
Scientific topics	The 'Galilei's thermometer: the real history and inventors. How does it work?
Target	High school students (second year)
Main chemical-related topics	Glassware, liquid and gas states of matters, expansion of gas and liquid, density of liquids, miscibility / immiscibility among liquids, solutions, concentrations, temperature-dependence of some chemical-physical properties.
Guided questions / inspiring questions to start the activity	How does the so called 'Galilei's thermometer' work? What are the principles of functioning? Do you know the history of this thermometer? Who were the real inventors of this thermometer? What are the uses of this thermometer? What is the sensitivity and what are the applications of this thermometer?
Methodology	Inquiry-based learning; cooperative learning; historical approach.
Timing	3 hours
Notes	This activity consists in three parts. First, students are divided in groups according to the cooperative learning method, some groups are invited to search for information about the so-called modern 'Galilei's thermometer' (see **Figure 4b**) and the principles of functioning. Other groups have a different task: search for the historical origin of this thermometer: why it is referred to Galileo Galilei and who are the real inventors? The second part of the activity is a collective discussion aimed at sharing the relevant information obtained by the groups. The third part is the preparation of a poster and some educational materials (i.e. brochures) about the history, scientific principles and main applications of this thermometer.
Main educational objectives	Understand the differences between thermoscopes and thermometers; understand the working principles of the Galilei's thermometer; understand the temperature-dependence of the density in liquids; search for scientific and historic information on resources on-line and read a scientific paper provided by the teacher concerning thermoscopes and thermometers.
	Activity n. 3 (third group of students)
Scientific topics	From the thermoscopes to the thermometers. Let's build our own instruments.
Target	High school students (second year)
Main chemical-related topics	Glassware, liquid and gas states of matter, expansion of gas and liquid, density of liquids, miscibility / immiscibility among liquids, solutions, concentrations, temperature-dependence of some chemical-physical properties.
Guided questions / inspiring questions to start the activity	What is the difference between a thermoscope and a thermometer? What are the basic principles of an alcohol thermometer? How is the graduate scale on a thermometer determined? What are the main uses of a thermoscope? And of a thermometer?
Methodology	Inquiry based and laboratorial activity

Relevant aspects	Description
Timing	3 hours
Notes	This is a laboratorial activity made of two steps. The first step is the building of a thermoscope and the second step is the calibration of a thermoscope to be used as a thermometer. These activities are relatively simple and the materials to be used are usually available (see for instance refs. 55 and 63).
Main educational objectives	Understand the differences between thermoscopes and thermometers; put into practice the scientific knowledge and design of a simple thermoscope; use common materials to build a thermoscope and a thermometer; acquire some practical skills related to the building of an instrument; estimate the sensitivity of the instrument; apply the instruments to measure the temperature of different systems.

(a) (b) (c)

Figure 4. Some of the thermoscopes and thermometers as object of the investigation and educational activities planned by the students. (a) An historical thermoscope similar to the ones contained in the collection of the science museum 'Galileo' (photo credit: Wikipedia: https://commons.wikimedia.org/);[55-57,62] (b) An example of a modern and commercial version of the so-called 'Galilei's thermometer' (photo credit: Wikipedia: https://commons.wikimedia.org/);[46,47] (c) draw of a thermoscope made by a student during the educational activities.

period of time) are very important from the educational point of view. Another aspect which merits some attention by the teachers is the counterintuitive functioning of the Galilei's thermoscopes with respect to modern bulb thermometers. In fact, the increase of temperature of the air contained in the ampule corresponds to a decrease of the level of the water (or alcohol or other coloured liquids) in the thick neck.

It's worth noticing that during the preparation of the educational materials of the three projects students used their creativity and skills related to their ability to draw, organize the materials and use interactive tools and resources. In this respect, several steps of the project allowed me to note the potentialities of a STEAM approach, combined with the effectiveness of the cooperative learning methodology.

As previously stated, undergraduate students could not put their projects into practice (step 7), which were planned during the second semester when the covid-19 pandemic started. The project concluded with the presentation of their cooperative works during the final exam of the course and the efficacy of the methodology was verified by analysing their feedbacks and final evaluation tests.[18]

5. CONCLUSIONS AND FUTURE PERSPECTIVES

The pilot study here reported concerns a structured method for training future chemistry teachers, called '*STEAM project-based learning*', which is centred on the role of science museums and historical scientific collections on learning science and, in particular, chemistry. As reported in this paper, the visit to a science museum represents a great stimulus for students and teachers, since a simple object in a collection can instil original ideas of how to approach a specific scientific topic or to build a non-formal activity related to a chemical concept. This methodology has been optimized within a course of 'chemistry education', as reported in refs. 2 and 18, and the feasibility of this approach at undergraduate level has been discussed. In the literature, other examples of activities about chemistry with educational approaches typical of science museums have been also reported at high school level.[2,5,7,64,65] All these experiences and research works demonstrated that non-formal hands-on activities centred on scientific museum or historical collections are very be effective in engaging students, improving their interest toward scientific topics and developing communication skills. As in the case reported here, where students decided to focus their attention on historical thermoscopes and thermometers held by the science museum 'Galileo' in Florence (Italy), the educational activities can be designed to include history of science in an interactive and constructive way,[30] with the aim to develop skills, which are usually indicated as higher order thinking skills, typically reached at the high school educational level. The STEAM philosophical approach is particularly suited for non-formal contexts, such as the science museum, and in this work, it is one of the key aspects of the methodology adopted during the course of '*Fundaments and methods of chemistry education*'. In the educational activities designed by the undergraduate students, the interdisciplinarity aspect is related to the main scientific disciplines, chemistry and physics, and to history of science, among humanistic disciplines. A key part of the project is the hands-on activity, since laboratorial activities need to have a high level of active participation in all steps, from the planning to the putting into practice, as also reported in other cases.[7,18,66] The only limitation of this project and in general of this educational approach is that it needs much more time than normal lessons, and it require a very good preparation by the teachers, who need to visit the museum in advance, prepare the materials and dedicate extra-curricular hours to let students work to their project. In the case study reported in this paper, it is important to underline that the undergraduate students who participated were able to explore some scientific concepts, such as the temperature, the temperature-dependence of density, the miscibility among liquids, the density as chemical-physical property of a chemical substance, by using non-formal educational methodologies starting from the investigation of the history of some objects collected in the science museum. Among the active methodologies at the basis of the activities designed by future chemistry teachers, the inquiry-based, cooperative and laboratorial learning methods were used in combination with the historical approach, which underlines the role of the 'humanistic' level in chemistry education teaching and learning models. From the evaluation of the project done by the students at the end of the course and from their final exam, I can conclude that this pilot project merits to be continued and implemented with the hope to be able in the next years to put into practice the activities planned by the students at the end of the project.

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