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The Role of Scientific Museums in Physics Education Courses for Pre-Service Primary School Teachers

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Abstract
Within the 2013-14 Physics Education Course for pre-service primary school teachers, we have developed an educational project involving the Museum of the History of Physics of Padua University and the Museum of Astronomy of Padua Astronomical Observatory. The main goals of the project were: (a) to stimulate in pre-service teachers a reflection on how scientific museums could be used for proposing effective and motivating scientific experiences within primary school curricula, (b) make them experience and recognize the advantages of an historical and narrative approach in the learning of a new subject. The presentations in the Museums focused on the relation between instruments and the evolution of scientific knowledge. Cosmological models from the ancient times up to eighteenth century were presented through instruments, paintings and significant narratives related to astronomers and physicists of the past. The effectiveness of the experience was evaluated through a written essay that students were asked to write at the end of both visits.

Keywords
Pre-service teacher education, astronomy education, museums.

1. Introduction and context of the project

In Padua, the physics education course for pre-service primary school teachers is organized so that most of the physics concepts are introduced through practical experiences. The course includes 60 hours of classroom lectures and 16 hours of laboratory activities. About 180 students attend the course every year and during the laboratory activities they are subdivided in groups of 30 people. The classroom lectures present and discuss basic physics concepts, together with an illustration of possible school activities that future teachers could organize at school to develop scientific knowledge and attitude in children, from kindergarten to the end of primary school.

Every year a particular topic is selected and several activities, including the laboratory on physics education, are dedicated to a deeper analysis of this special topic. The idea is to illustrate through a particular example how each topic needs to be explored at various levels along the whole school period. Particular emphasis is put on everyday experiences of the phenomena under study and on interdisciplinary connections, in order to help future school teachers to develop scientific educational projects meaningful for young students.

From 2014, the course was reorganised according to the National Indications of the reformed university curriculum for the graduation of primary school teachers. One of the main changes introduced by the new Indications was the requirement to include some basic astronomical topics in the physics education course. For this reason, in the academic year 2013-14, the special topic of the course was "Astronomy", which was explored through various activities in classroom and outdoors, in laboratory and at museums.

In the classroom, one of the activities was the construction of a quadrant with cardboard, string and a small weight; this activity was done in collaboration with the teacher of mathematics education. The quadrant is an instrument used to measure angles up to 90^0: it can be used for measuring the position of sky objects, like stars, the Sun and the Moon, but it can also be used for measuring the height of buildings. It is worth mentioning that quadrants were widely used in Europe during the Renaissance and the sixteenth century in astronomy, time measuring and surveying. In figure 1, we see students outdoors learning how to use a quadrant for measuring the height of a building.

Figure 1. Outdoors activities: learning how to use a quadrant.

In the laboratory, students first explored the properties of light, in particular the characteristics of the shadow produced on a screen behind an object in relation with the position and extension of the light source. These experiences helped them to construct the straight-lines model of light, useful for interpreting astronomical observations, like day and night alternation. The straight-lines model was then used for interpreting reflection and refraction phenomena. The second part of the laboratory was dedicated to the analysis of astronomical phenomena, like the length of day and night at different latitudes, the characteristics of lunar phases in relation to the Earth, Moon and Sun's relative positions. For these explorations students used light sources and spheres as physical models for representing the Earth and the Moon (see figure 2).

Figure 2. Modeling the Earth-Moon-Sun astronomical system.

Finally, in tight connection with the activities just mentioned, a project was developed in order to plan and organize specific visits and activities at the Museum of the History of Physics of Padua University and at the Museum *La Specola* of Padua Astronomical Observatory. The project was the fruit of the collaboration of the three authors of the present paper, Ornella Pantano, who is in charge of the Physics Education course, Sofia Talas, the Curator of the Museum of History of Physics, and Valeria Zanini, the Curator of the Museum *La Specola*.

The advantages of a historical approach in the learning of a specific subject is well documented in the literature [see e.g., Monk & Osborne,1997; Rudge & Howe, 2009], but the actual state of implementation of this approach in schools is still poor due to the difficulty of finding and adapting history-based teaching material and the lack of pedagogical content knowledge necessary for confident and effective teaching [Henke & Höttecke, 2014]. We think that one of the ways to deal with these problems could consist in

exposing future teachers to a personal experience of learning paths in historical scientific museums. Two of the authors have a wide experience in developing thematic paths in physics for secondary school students with laboratory activities and visits to the Museum of the History of Physics [Pantano & Talas, 2010]. This was the first experience with undergraduate students doing a primary school teacher degree.
After an outline of the two Museums involved in the project, the paper will describe the main goals of the project, its content and some final considerations on its outcomes.

2. The two Museums involved, a short presentation
Both the Museum of the History of Physics and *La Specola* keep important collections of physics and astronomical instruments, heritage of the fruitful scientific activity at Padua University throughout the centuries. Historical instruments, working places and paintings constitute windows to examine and understand the way cosmological models evolved throughout the centuries.
The Museum of the History of Physics houses the instruments that were invented, made or used at the University of Padua to carry out physics research and teaching [Talas, 2012; Talas, 2013]. A first nucleus of instruments was collected for the lecture courses on Experimental Philosophy – Experimental Physics in modern terms - that were introduced at the University of Padua in 1738. Giovanni Poleni, who was assigned the new chair, gathered a first group of machines within a couple of years and he continued to enrich the collection until his death, in 1761. His successors went on acquiring new instruments both for teaching and research, including objects that already had an historical value. The Museum thus has some sixteenth- and seventeenth-century devices, but the main part of its collection is made of instruments of the eighteenth, nineteenth and twentieth century.
The other museum involved in the project was *La Specola*, which preserves the instruments and historical heritage of the Astronomical Observatory of Padua, one of the main structures of the National Institute of Astrophysics (INAF) [Pigatto, 2007]. The Astronomical Observatory of Padua was founded in 1761, within a complex program of reform that the University of Padua developed in order to instruct the students in the practice of experimentation. The high tower of the old city castle was chosen as the best place where to build the Observatory, which was made of two parts: a lower observatory, flanking the east wall of the tower at a height of 16 meters from the ground, and a higher one, at 35 meters, on the battlements. The lower observatory was later called the Meridian Room. Here, the local time at midday was measured along the meridian line carved in the floor, and stars were observed in their transit across the celestial meridian. The upper observatory was dedicated to observations with telescopes of various types, which could be pointed in different directions and also moved outside, on the terrace surrounding the tower. The museum collection includes telescopes, globes and quadrants of the eighteenth and nineteenth century. All the instruments are placed in the rooms where the astronomers used to work in the past.

3. The main goals of the Museums Educational Project
The project has been developed within a course in which prospective primary school teachers learn both some basic physics and astronomy topics and how to teach those subjects to young children. For this reason the goals of the project concerned both the discipline and its teaching.
From the point of view of the discipline, the aims of the project were to present to the students the principal steps in the evolution of cosmological models across centuries and, at the same time, outline some important features of scientific methodology. Cosmological models from the ancient times up to the eighteenth century were presented using instruments, paintings and narratives related to astronomers and physicists of the past. The important features of scientific methodology were discussed through the storytelling of some of the events that led to the development of new models and theories. The description of some historical instruments and the story of their role in scientific discoveries was very effective in showing the relationship between instruments and the evolution of scientific knowledge. This relation between the advance of technology and the growth of scientific knowledge is a theme very important also today.
From the point of view of physics and astronomy education, the main goals of the project were (a) to stimulate in pre-service teachers a reflection on how scientific museums could be used for scientific education in primary schools and (b) make future teachers experience and recognize the advantages of a historical and narrative approach in learning a new scientific subject. In order to attain those goals, we exposed pre-service teachers to the same kind of experience that they could propose in the future to their students.

4. The Museums Educational Project

The Museum Educational Project proposed to the students one visit of about 1,5 hour at each Museum. The students could participate on a voluntary basis but, as the Physics Education Course is attended by around 180 students and as there were many requests for participation, it was decided that groups of 30 students would be created. These groups were then divided in two sub-groups of 15 people, so to facilitate the interaction between the students and the Museums' staff. The idea was to start from the objects and from the buildings, in order to extract from them information and details.
In tight connection with the topics treated at the Physics Education Course, the visit at the Museum of the History of Physics focused on two groups of instruments: a couple of astronomical Renaissance instruments – an astrolabe and an armillary sphere -, and the optical instruments of the Museum, with a particular focus on telescopes and microscopes.
We started from the observation of the astrolabe and the armillary sphere and, at first, we discussed the stories of the people around these objects. Who made them? Who used them, and so on? The astrolabe for instance, is signed "Renerus Arsenius Nepos Gemme Frisy Faciebat Louany 1566" and it is worth reminding that Arsenius worked in Louvain with Gemma Frisius, mathematician, cartographer and inventor of scientific instruments (figure 3).

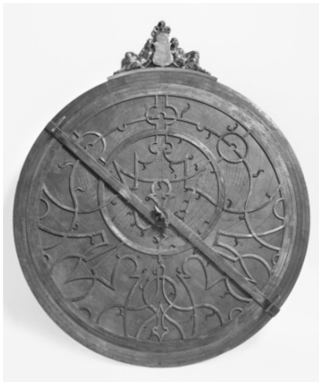

Figure 3. Astrolabe by Renerus Arsenius, Museum of the History of Phsyics, University of Padua

We examined the way these instruments were used and, as for the astrolabe, this was made easier because the students had already made and used a quadrant during the Physics Education Course. But there is much more information lying within these objects. They tell about the theories and models of their time, in this case about the Ptolemaic-Aristotelean model of the universe, with the Earth unmoving and located at the center of the Universe. They also tell about the role of scientific instruments in the Renaissance. At that time, mathematics was applied not only to transform the art of painting through the introduction of perspective, but it was also applied to the needs of the other arts through the invention or the improvement of instruments. Gnomonic, astronomy, the art of topography, the art of navigation and the military art were thus transformed by the so-called "practical mathematics". Several Renaissance engravings, showing the use of astrolabes and other instruments for surveying or even military uses, were presented to the students in this sense. However, it was also crucial to underline to the students that these instruments, used as models and/or for measurements and calculations, were not regarded at that time as possible conveyers of new knowledge about Nature. The latter was only the matter of philosophers and it was based on Ancient texts. Observations and measurements could not significantly change the accepted models of the World.
Renaissance instruments nevertheless started to be regarded as symbols of power, as they were crucial for navigation and surveying of the newly discovered countries. It is not by chance that Manoel I of Portugal included in his flag an armillary sphere at the end of the fifteenth century, and that armillary spheres became part of the Manueline architectural style. Instruments were also regarded as symbols of knowledge, and lots of them were included in paintings by Renaissance artists like Giorgione, Vittore Carpaccio, or Hans Holbein the Young. Scientific instruments became in those years symbols of social status as well, so that astrolabes, armillary spheres and quadrants were included as part of the Wunderkammer, the Renaissance noble collections. In this sense, instruments thus also tell us about the connections between science and the society of their time.
The second part of the visit to the Museum of the History of Physics then dealt with telescopes, microscopes and other optical instruments. Here again, details were given about the single instruments, their inventors, makers and users. However, as in the case of the astrolabe and armillary sphere, there is much more

information to be extracted from telescopes and microscopes. They are among the main instruments that marked the Scientific Revolution. Telescopes, in particular, were crucial to observe the sky and look for confirmations of the Copernican Model, the newly proposed model of the Universe, in which the Earth and other celestial bodies move around the Sun. Moreover, they marked the introduction of a totally new way of studying Nature. Galileo refused to base himself on the authority of the Ancient scholars and on what he called a "mondo di carta". He wanted to read "the book of Nature" and used instruments to do so. Instruments thus became the essential media between Man and Nature: this was a totally new role for instruments, which became crucial for scientific research, thus marking the birth of the so-called Scientific Method. Moreover, a new link between Science and Technology was established, a link which is still one of the main features of Modern Science.

At the Museum *La Specola* the aim of the visit was not only to see the ancient instruments, but also to observe the whole building, which represents itself a scientific instrument.

The visit began with the video "Ancient Heavens", which illustrated the special relationship that humanity always had with the sky. Since ancient times, in fact, an eternal and perfect order was felt in the great sky, conflicting with the transience of everyday life. A geocentric picture of the Cosmos consolidated in the Greek era and survived until the mid-sixteenth century, when the Polish astronomer Nicolaus Copernicus proposed his new model of the Universe. The video thus reminded the evolution of cosmological models, already discussed at the Museum of the History of Physics. It also emphasized the crucial role of the *habit to observe* the sky, which was typical of ancient men, an habit which is today very rare not only in students, but in teachers as well.

The visit continued in the Meridian Room and focused especially on the meridian line and the mural quadrant. The meridian line was carved in 1776 and, on this line, the true midday of Padua Observatory was measured by the Sun's luminous image projected on the floor through the gnomonic hole placed in the south wall of the room. This was the first important device used by astronomers to measure the time and to set clocks; but we also showed to the students its usefulness today for understanding the movement of the Sun on the celestial sphere throughout the year. The students' attention was then focused on the mural quadrant, made by the famous instrument-maker Jesse Ramsden and installed in the Meridian Room in 1779. The mural quadrant was used to measure the height of stars above the horizon at their transit at the celestial meridian. It was an extremely precise instrument for that epoch and students were explained that, in order to ensure the maximum exactness in hand-made graduations and avoid errors in divisions, mural quadrants were built very large: in this case the quadrant radius is 244 cm. Future teachers could thus appreciate the close link between scientific knowledge (mathematics and astronomy in particular) and the technical skills of manufacturers.

Reinforcing what had been shown at the Museum of the History of Physics, the Meridian Room provided the students with another practical example on how the Scientific Revolution implemented the new methodology of knowledge both through observation and experimentation, and through the central role of instruments.

Figure 4. The fresco in the Meridian Room showing the Solar system before 1781, Museum *La Specola*.

Highly instructive was also the large fresco painted on the east wall of the Meridian Room (figure 4). This fresco shows with considerable accuracy the geometrical configuration of the model of the solar system before 1781 and it was for students an efficient visual summary of the astronomical knowledge at the end of the XVIII century.

The visit ended in the Figures Room (figure 5), where eight life-size full-length portraits of famous personages in the field of astronomy are painted all around the walls. They are, in chronological order: Ptolemy, Nicolaus Copernicus, Tycho Brahe, Galileo Galilei, Johann Kepler, Isaac Newton, Geminiano Montanari and Giovanni Poleni. The students were told about the scientific activity of these personalities, whose contribution to the development of scientific knowledge and the evolution of cosmological models was fundamental.

Figure 5. Students looking at pictures and listening narratives related to important astronomers of the past in the Figures Room, Museum *La Specola*.

5. Assessment and conclusions

The impact and effectiveness of the experience have been evaluated through a questionnaire that students answered at the end of each visit. The questionnaire was built in order to analyse, first, which part of the learning situation surprised them and arose the greatest interest towards the discipline and the particular subjects treated in the visits. Second, the questions also aimed at stimulating a reflection on how they could use the same context for inspiring in young children an interest toward physics and astronomy. These questions indirectly gave us a hint of the activity that was more inspiring for the future teachers themselves. The principal questions proposed were:

- What attracted you most and what would you like to know more about?
- What surprised you?
- What theme would you choose to deepen with the children?

An analysis of the answers has shown that many aspects of the project stimulated students' interest. They all were very impressed by the amount of information that a single instrument can infer and also by the beauty and perfection of ancient apparatus. In the following, we give some examples of particularly significant answers.

At the Museum of History of Physics:

What attracted you most and what would you like to know more about ?

- "*I found very interesting the part in which we have been explained about the scientific instruments used by the ancients (astrolabe). To see instruments is always very useful for understanding.*"
- "*There were many interesting objects, but the attention has been particularly attracted by the objects that we have reproduced during the lectures, as the octant which is similar to the instruments [quadrant] which we have constructed for measuring distances.*"

What surprised you?

- "*I was fascinated by the number of stories that a single instrument could evoke. Certainly children could absolutely be involved by the history of objects and the history of physics.*"

What theme would you choose to deepen with the children?

- *"I would choose optics [..]: I think that, with an appropriate presentation, it can be proposed at any age as it is amazing also for grown-up people."*

At the Museum of Astronomy:
What attracted you most and what would you like to know more about ?

- *"I was intrigued by the Meridian Room and I wonder with which instruments they built the line of meridian, how they decided where to put the hole in the wall in such a way that the sun could reflect [sic] exactly on that line."*

What surprised you?

- *"I was very impressed by the fresco in Meridian Room, which represented the Universe known until about the 17th century. I was impressed by the precision with which it has been done."*

What theme would you choose to deepen with the children?

- *"With children I would deepen the Figures Room, using the magnificent frescos to narrate the history of astronomy, as pictures are a very good tool to use for presenting a new subject."*

The analysis of the answers showed what were the aspects of the presentation which most impressed future teachers and we could see that both of the goals behind our project were reached.
Students were impressed by the stories on the role of instruments and technology in the development of scientific knowledge and so, implicitly, they showed to appreciate the use of scientific museums and historical instruments for presenting scientific issues. In order to check the effective impact of this kind of experience, it would be worth planning an investigation to examine whether teachers who had experience of science museums in their education, more frequently include visits to scientific museums in their science teaching activities.
The students also recognized the advantages of an historical and narrative approach, as they outlined this aspect in most of the answers. Many of them also said they would choose this approach for their future teaching of astronomical issues. One could also plan an investigation on this point, to ascertain whether teachers who experienced an historical and narrative approach in their science education, would really use it in their science teaching.

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