

Astronomy at school: An educational proposal to experience physics in high school

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received 28 February 2023

Summary. — Astronomy is a valuable tool for introducing young people to scientific disciplines and physics in particular. In addition to arousing curiosity, in fact, it allows numerous physics topics to be addressed: from the concept of field and force to the laws of dynamics, from Kepler's laws to optics, from nuclear physics to relativity. In this article we present a physics course aimed at high-school students and which covers the treatment of some topics in astronomy. The course, which lasted a total of 20 hours, was highly appreciated by the participants.

1. – Introduction

The fascination aroused by astronomy can be a powerful means of bringing even the youngest people closer to the world of science. In recent years, in fact, more and more organizations are making efforts to develop and disseminate educational activities that are based on astronomical themes or involve the analysis of real data used by scientists [1-3].

Using astronomy as a guiding thread, at the University of Roma Tre we decided to propose a course of activities that would allow students to enter the world of physics in a practical way and to discover and explore from a new point of view some topics that are already part of the school curriculum: from the laws of motion and Kepler's laws to the electromagnetic spectrum and General Relativity. In this article, we will present the astronomy path we developed and then offered to high school students, which introduces some current research topics and allows students to use real scientific data.

2. – Methods

To build our course, we took advantage of the opportunity offered by the “Percorsi per le Competenze Trasversali e l'Orientamento - PCTO” [4] (Educational paths for soft

skills and orientation), which establish the obligation for students in the last three years of Italian high school to supplement traditional classroom training with training periods concerning orientation activities. In this context, we have in fact developed a 20-hour course on astronomy and implemented it with two classes, a third class of the classical high school and a fourth class of the scientific high school. The course consists of 10 meetings of 2 hours each. All the meetings were designed to be held by a university tutor at school or university, but they can also be adapted with a few modifications to be delivered online in the event of restrictions due to the COVID-19 pandemic, as unfortunately actually happened for 3 meetings held online with one of the two classes.

The course begins with two interactive lectures that provide an introduction to astronomy and the topic of astronomical distances and deal with the exploration of space around the Earth, also through a virtual journey in the Solar System. Subsequently, 7 laboratory-type meetings are proposed, based on individual activities already established and implemented locally (at the Università Roma Tre), nationally or internationally. 3 involve the use of computers and planetarium software, 2 of these activities were chosen because they are poor laboratory experiences, and can therefore be easily replicated later and independently by teachers or by the students themselves in other classes at the end of the course, 1 of these activities were also chosen because they allow the process of research in physics to be retraced, presenting physics topics through the real data used by scientists, and having the students analyse them directly, 1 with scientific instrumentation (telescopes and thermal sensors).

During all practical activities, the students work in groups with the guidance of the tutor who also stimulates discussion within individual groups and then collective discussion with the whole class.

At the end of the course, a meeting was then held on a topic of the participants' choice, enabling them to explore topics of particular interest to them. The first class chose to tackle the topic of the Milky Way and the other galaxies, while the second class chose to explore the topic of time in physics and the physics of time.

The 7 laboratory meetings are described below.

3. – The 7 practical activities proposed

3.1. Experience 1 - Introduction to the use of the planetarium software Stellarium. – The aim of this experience is to familiarise participants with the planetarium software, which will also be used for other experiences in the proposed course, through the narration of myths linked to certain constellations and some simple exercises. In addition, the experience aims to make participants experience the apparent motion of the celestial sphere, through the observation of stars that may be circumpolar or may rise and set depending on the location of observation.

In the first part of the meeting, we chose to use the theme of the constellations as a guiding thread. The tutor shows the class some constellations and the basic commands of the Stellarium simulation software [5], then asks the students to repeat some operations to familiarise themselves with the software. In the second part of the meeting, the students are divided into small groups (2 or 3 people) to encourage comparison during the phase in which they carry out measurements using Stellarium. In this phase, the tutor asks the students “What are the sunrise and sunset times in Rome on 21 January 2021?” and gives the students a few minutes to formulate an answer based on what they can experience using the planetarium software. The tutor then stimulates the discussion by pointing out that the groups' results are different from each other and asks the students to formulate hypotheses on the possible explanation. They then arrive at the need to

all define together the object of measurement, in this case sunrise and sunset. Next, the tutor asks the participants to identify and note the height of the North Star and the Mizar star at one-hour intervals for 24 consecutive hours. Again, the tutor leads the discussion on why the former star had minimal variations in height while the latter had considerable ones. Finally, the tutor asks to identify some data, the latitude of the location, the star visible to the naked eye closest to the celestial pole (north or south), the height above the horizon of the fixed star, which constellations rise and set, for different locations distributed in both the northern and southern hemisphere. After projecting the data collected by the groups onto the screen, the tutor stimulates discussion on the apparent motions of the celestial vault due to the Earth's rotation and the latitude of the observation site and the consequences of the tilt of its axis.

3.2. *Experience 2 - Stellarium to study the illumination of the Sun on Earth.* – The aim of this experience is to improve the participants' skills with the Stellarium software and at the same time to make them think about time zones, seasons and the apparent motions of the Sun. In this meeting we therefore introduced concepts that would later be taken up and developed in Orientated Globe Experience 3. In particular, after dividing the participants into small groups, the tutor asked: "Find the sunrise and sunset times for the following cities for the day 21 January 2021: Rome, Vico del Gargano and Trapani." Vico del Gargano was chosen because it is at about the same latitude as Rome and Trapani because it is at about the same longitude as Rome. The tutor then collects the data obtained from the students, and points out how the times of sunrise and sunset change by moving along a parallel or along a meridian. The tutor then asks the participants: "Set Rome as the location and, varying the time with intervals of one month for 12 consecutive months, find the maximum height above the horizon that the Sun reaches each time and at what time this occurs". At this point, the tutor stimulates discussion on the relationships between the time of year, the maximum height reached by the Sun and the time at which this occurs. In particular, given the difficulty in finding relationships just by looking at the data collected by all the groups, the tutor puts their measurements on a graph and analyses it with the students, dwelling on the usefulness and importance of visualising the data graphically.

3.3. *Experience 3 - The orientated or parallel globe.* – In this experience, thanks to a poor laboratory, participants are made to experience the condition of the Earth's illumination in real time, and concepts such as time zones and seasons addressed previously are taken up. The instrument used is the orientated globe or parallel [6,7]. The materials are easy to obtain: all that is needed is a globe, some toothpicks and suction cups [8]. The participants are divided into two groups and after a brief explanation on the use of the equipment, the two groups orient the globe so that the axis is parallel to the Earth's axis and the location is at the highest point. Using toothpicks and suction cups, they then compare the shadows produced in the city of Rome with those of other locations on the same parallel or meridian. The tutor then leads the discussion on the concepts of time zones and seasons.

3.4. *Experience 4 - Observation of the Sun through a telescope.* – The purpose of this experience is to have students observe sunspots with a simple and safe instrument, then deepen their knowledge of the Sun and its characteristics. Specifically, participants observe the Sun through the Solarscope [9], which is an inexpensive solar telescope that projects the solar disk inside it and thus allows them to safely observe sunspots. Although it is a simple instrument and not a professional telescope, the Solarscope allows students

to acquire real data by observing the sunspot phenomenon live. After the observation, the tutor, through a presentation, takes up and describes the sunspot phenomenon and also presents the other main features of our star as well. To do this he shows some real data used by scientists, who then introduce the topic of observing the Sun with different instruments and in different bands of the electromagnetic spectrum. At this point the tutor shows what can be observed using a thermal camera, filming students and some objects in the classroom live, just as an example of an instrument capable of observing in a band other than the visible one. Finally, the tutor shows students that today it is possible for everyone to use more advanced instruments to observe the Sun at any time, taking for example data from the SDO space telescope that is always available online [10].

3'5. *Experiment 5 - Does the Sun revolve around its own axis?* – The purpose of this meeting is to formulate hypotheses about sunspots and question their nature, reproducing Galileo's historic experiment with modern data.

In fact, in this meeting the participants analyzed real data, from the Solar Dynamics Observatory (SDO) space telescope. Following the activity developed in [11], students observed 30 images of the Sun recorded one per day, around the same time, for 30 consecutive days. The tutor then asked the students, divided into small groups, to formulate hypotheses about the nature of the dark spots in the images of the Sun they were observing. He then led the discussion to compare their proposed hypotheses: starting with the possibility that these black spots were a problem due to the instrument, a phenomenon present in the Earth's atmosphere, a celestial body orbiting the Sun or finally a phenomenon of the solar surface. Again divided into groups, he asked the students to reason about how they could discard as many hypotheses as possible, going through the basic steps of the scientific method. After a guided discussion, the students come to the conclusion that the best hypothesis is that the Sun rotates, thereby causing the apparent motion of sunspots on its surface. At this point, the groups reflect on how to measure Sun's rotation period from the SDO data available to them. Finally after a guided discussion, each chose their own method and measured the rotation period.

3'6. *Experience 6 - Measuring the mass of Jupiter with Stellarium.* – The purpose of this experience is to calculate the mass of Jupiter using Kepler's laws applied to the orbits of Galilean moons observed and measured with Stellarium [12]. The tutor points out that one can approximate the motion of Galilean satellites to a uniform circular motion and, using the law of Universal Gravitation, one can find a simple relationship between the planet's mass, period of revolution and average orbital distance of any of the planet's satellites. The students, divided into small groups, reflect on how to make the period and distance measurement, and finally the tutor leads the discussion during which each group shares their idea, gathering advice or considerations from their peers. Each group then chooses its own procedure and collects data. Finally, the obtained measurements are commented together.

3'7. *Experience 7 - Discovering spacetime.* – The goal of this experience is to introduce some of the aspects of Einstein's theory of General Relativity through the elastic cloth. In particular, we used the kit designed at Roma Tre University that can be made with poor and easy-to-find materials [13]. A total of three kits are used in this activity, one of which is used by the tutor and the other two by the participants. Following the activity sheets in the ebook *Experience gravity with the rubber sheet: guidelines and tricks* [14], we then start by experimenting with Kepler's laws and then go on to cover topics such as gravitational lenses and black holes.

4. – Participants’ feedback

At the end of the course we asked all participants to fill out an anonymous questionnaire. We received 34 responses out of a total of 45 participants. The questionnaire consisted of closed-ended and open-ended questions; to the former, respondents could answer, “Not at all”, “A little”, “Quite a bit”, “A lot”, and “Completely.”

To the question “Do you think it was worth participating?” 15 responded “Completely”, 9 responded “A lot”, 6 responded “Quite a bit”, 2 responded “A little”, and 2 responded “Not at all.”

When asked if they would recommend the course to a peer, 1 responded “Absolutely”, 5 responded “Certainly”, 20 responded “Yes”, 2 responded “If interested in astronomy yes”, 1 responded “Quite a bit”, 1 responded “Yes, because it is conducted during school hours”, 1 responded “I don’t know”, 2 responded “No”, and 1 did not respond to this question.

For each meeting, we asked respondents how interesting they had found it. Looking at the whole course in total 166 times they answered “Totally”, 108 times they answered “A lot”, 52 times they answered “Quite a lot”, 3 times they answered “A little”, especially for the meetings “Does the Sun revolve around its axis?”, “Observation of the Sun through a telescope” and “Measuring the mass of Jupiter with Stellarium” and 11 answered “Not at all”, particularly for the meetings “Let’s explore the space around the Earth”, “Virtual journey in the Solar System, the problem of distances in astronomy”, “Stellarium to

TABLE I. – *This table shows for each meeting the responses to the question “Was the meeting interesting?” Respondents could answer “Not at all”, “A little”, “Quite a bit”, “A lot”, or “Completely.” All of the meetings were held in both classes, except for the meetings “The subject of time in physics and the physics of time” and “The Milky Way and other galaxies” as in-depth studies each were requested by one of the two classes.*

	Not at all	A little	Quite a bit	A lot	Completely
We explore the space around the Earth	3	0	6	11	14
Virtual trip to the Solar System, the problem of distances in astronomy	3	0	6	11	14
Introduction to the use of the planetarium software Stellarium	0	0	4	10	20
Stellarium to study the illumination of the Sun on Earth	1	0	4	13	16
The Orientated or Parallel Globe	1	0	5	15	13
Observation of the Sun through a telescope	1	1	4	14	14
Measuring the mass of Jupiter with Stellarium	0	1	4	7	22
Discovering spacetime	1	0	5	9	19
The topic of time in physics and the physics of time	0	0	7	4	11
Milky Way and the other galaxies	1	0	1	3	7
Total	11	3	52	108	166

study the illumination of the Sun on Earth”, “Observing the Sun through the telescope”, “Discovering spacetime ” and “The Milky Way and other galaxies.” The detailed results are shown in table I.

When we polled which topic they liked the least 11 participants answered “Measuring the mass of Jupiter with Stellarium”, 6 answered “The Orientated or Parallel Globe”, 4 answered “Does the Sun revolve around its own axis?”, 3 answered “The topic of time in physics and the physics of time”, 3 answered “Observation of the Sun through a telescope”, 2 answered “Let’s explore the space around the Earth” and “Virtual trip to the Solar System, the problem of distances in astronomy”, 1 answered “Stellarium”, 1 answered “None”, 1 answered “Measurements, 1 answered “Kahoot!”.

Finally, we asked the respondents what they would eliminate from the program:

20 answered “Nothing”, 4 answered “Measuring the mass of Jupiter with Stellarium”, 2 answered “I don’t know”, 1 answered “All things concerning too long a calculation”, 1 answered “The Orientated or Parallel Globe”, 1 answered “Discovering spacetime”, 1 answered “Kahoot!”, 1 answered “Time in physics and the physics of time”, 1 answered “Let’s explore the space around the Earth” and “Virtual trip to the Solar System, the problem of distances in astronomy”, 1 answered “Does the Sun revolve around its own axis?”, 1 did not answer.

5. – Discussion and conclusions

In this paper, we presented a 20-hour course that uses astronomy as a thread to talk about physics and for students to experience the scientific method firsthand with hands-on activities. It took particular advantage of the PCTO hours that students are required to take by law, and thus was able to address a large group of participants.

The students were participatory and frequently asked questions, including about topics we had not planned to cover or about the general workings of the university and the physics curriculum. Our impression is that most of the participants were engaged and actively participated. Indeed, from our direct experience and from the results of the final evaluation questionnaire, there is an overall positive feedback from both the students and their faculty.

Most of the students surveyed, more than 80 percent, not only say that it was definitely worthwhile to participate in this activity, but even 88 percent would recommend this experience to one of their peers. Overall enjoyment of the individual meetings also emerges, with at least 91 percent of participants finding them interesting. The only negative element that emerged from the analysis of the individual meetings lies in the fact that some participants would have preferred not to have to use some mathematical calculations. For example, in the experience of measuring the mass of Jupiter, a portion of the respondents say they found difficult both the mathematical step of turning an angular distance into a linear distance and the equivalence of seconds, primes and degrees with radians. This problem can be overcome by supporting students more in the calculation step, for example by showing the necessary formulas on the screen and guiding them in their use. In addition, some students reported that the distance meetings were less clear and more difficult to follow. However, this aspect should not burden the next repetitions if there is no need to use distance learning anymore for the pandemic of COVID-19.

The teachers also expressed their enjoyment in the course. In fact, they particularly appreciated the tutor’s commitment in spurring the participants to reasoning, including group reasoning, to answer the questions and problems that were posed. In addition, the use of real data in astronomy experiences allowed not only to show how scientists

analyze and process data, but also to carry out activities that a lecturer can hardly do independently.

The integrated use of resources and activities developed over the years by various astronomy groups, both Italian and international, using simulations, poor laboratory and scientific data, and which are nonetheless expendable in school, has allowed students to experience scientific reasoning firsthand from different perspectives.

Astronomy thus seems to have been confirmed as a medium that engages students and encourages them to actively follow the proposed activities, proving to be also useful as a guiding thread of the course and offering insights for participants to apply the scientific method in different areas. In addition to having participants develop extracurricular knowledge, astronomy has also enabled them to develop skills on the scientific method that need to be acquired at the end of their schooling.

These elements, therefore, make us think that our proposal proved to be a good one, and it allowed them to deepen their understanding of scientific reasoning and method.

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This work was supported by the Italian Project “Piano Lauree Scientifiche.” Thanks to Nicoletta Lanciano for the Globolocal project that spread the use of the oriented globe in schools. The authors also thank EuroVO and Astroedu for developing the clear and useful activities to address the topics covered.

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