Astronomy laboratory for 13-to-15-year-old students

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Abstract. In this work, we suggest the use of astronomical laboratory topics in didactic activities. We present two educational experiences, which we offered to last year students of the junior high school and first-year students of the technical-economic high school (ITES). Astronomy attracts the majority of students. Our idea is to use this interest as leverage to show how concepts and tools of Mathematics and Physics are essential; therefore the study of Mathematics and Physics topics becomes more explained and fascinating. For every laboratory activity, we explicate some of the Math, Physics and Astronomical concepts that can be strengthened. Every step was enriched by a brief theoretical presentation of some current research in the astronomical field, to increase the interest of students. We propose to use simple and cheap materials for all the laboratory experiences, and we suggest also using smart-phone applications as physical tools. We present three laboratory activities for the younger students and two laboratory activities for the older ones. For every topic we proposed a pre-test, to check out previous knowledge, and a post-test, to reflect if students have achieved the goals. We report the teacher's opinion to draw some conclusions about the work done. In the end, we underline some problems and difficulties encountered.

1. Introduction
An ancient Chinese saying states that: “If I listen to something, I’ll forget it; if I see it, I’ll remember; if I make it, I’ll understand”. Furthermore, a study that was done by Observa Science in Society [1] shows that Italian high school students who had the opportunity to use a scientific laboratory during their school experience are three times as likely to intend to choose a science degree course. Our experience too confirms that laboratory activities improve students' attitude towards science. Besides, Italian students show a great interest in astronomical topics, as pointed out by the statistical survey ROSE (Relevance Of Science Education) [2]. On the contrary, they consider “hard to understand”, boring and abstract (if not even useless) subjects like Mathematics and Physics, as stressed by ANISN (National Association of Natural Science Teachers) [3].

We propose to use astronomical topics in laboratory activities, so students have to apply mathematical and physical concepts in a fascinating way. One of the crucial problems is that not all schools have laboratories with appropriate scientific tools and devices. To overcome this problem, we have studied laboratory activities carried out with simple and cheap materials, also suggesting the use of smartphone applications as physical instruments [4]. Astronomical subjects are appropriate to realise simple laboratory experiences and to introduce the scientific method [5].

The activities were developed and realised for students attending the last year of first grade secondary school (ages: 13–14) and for first-year students of a technical high school (ages: 14–15). In fact, the Science syllabus for these classes includes “astronomical arguments”, and we believe that this link can
be significant also for the teachers. Moreover, astronomical subjects are often not well understood [6–8].

2. Overall aims of the astronomy laboratory activities
We have identified five main aims to the astronomy laboratory activities:

- To obtain a more clear and exact knowledge of some basic astronomical concepts, such as the dimensions of the solar system, the significance of Kepler’s Laws, the difference between a star and a planet, the concept of habitability zone. All these arguments can be related to current research topics in the field of astronomy, thereby increasing the interest of the students.
- We developed practical but easy activities made up of cheap and easy-to-find material; so students can acquire the data of the laboratory activities without sophisticated instruments.
- We have some physical aims: in fact, by simple experiments the students can learn some primary laboratory methodologies; they can use simple physical instrumentation and understand what the method of data acquisition is. Essential becomes the construction of tables and graphs (also with the use of a spreadsheet), their interpretation and even the methodology of writing a physical result.
- From a mathematical point of view, we obtain a refreshed and in-depth comprehension of basic mathematical topics, such as proportions, geometrical formulae, use of the Cartesian plane, direct and inverse proportionality…
- Last but not least, we want to point out that laboratory activities strengthen the work in a team and that all the events are designed to be inclusive.

3. Structure of the activities
We based each activity upon one astronomical topic. At the beginning of each laboratory, students have to answer to a test to check out previous knowledge of the matter in question. Then a brief theoretical presentation introduces the subject and the practical activity. The central part of the exercise is the realisation of the “apparatus”: students have to work in the construction, in the data acquisition and then in the analysis of the experimental data.

Significant is the following part in which all the class discusses the results. Unfortunately not always there was the time for this discussion, but we noticed that its lack makes less efficient all the activity. This fact results evident from the final tests that we used at the end of the laboratory to find out if the students have achieved the goals of the practical activity.

4. Junior high school students’ activities (13-to-14 years old)
We performed the laboratories in four classes, and we had three activities, each one lasting two hours. The activities’ titles are: ‘The solar system’, ‘The Sun’ and ‘Planetary transit’.

4.1. First activity
In ‘The solar system’ lesson we start with the comparison between the Ptolemaic and Copernican models. What is the “Solar System”? What is the difference between stars and planets? These are also the suggestions that we offer to the students in the pre-activity discussion. Then we focus on planets, their features and their motions, adding curiosities about each planet to help their identification.

The practical activity is the construction of a “human orrery”, based upon the description in the article by Newbury [9], who was inspired by the design of the Armagh Observatory in Ireland [10, 11]. The activity requires a wide place, so we chose to realise it in the gym of the school (figure 1). The “human orrery” is a model of Solar System that reproduces to scale both the distances of the Solar system planets from the Sun and the time they need to go along their orbit; it is called “human” because students act the part of planets. This tool helps students to understand planetary motion and in particular Kepler’s third law, as they can directly visualise the position of each planet along its orbit. At the same time, students became aware of the dimensions of the solar system and the realistic distances between its components.
The complete activity requires a lot of time; while one group of students works to the practical action, other groups have to resolve some exercises linked with the tool, and this helps them to understand and to strengthen the information they obtained. From the mathematical point of view, these exercises improve students’ ability on the setting and the resolution of proportions. About the link to a topical subject of interest, we worked with them about the time that a signal takes, when it starts from Earth, to arrive at a spacecraft on Mars, both when it is in opposition and when it is in conjunction. In this way we have the opportunity to define and clarify what opposition and conjunction mean.

4.2. Second activity
The second activity is ‘The Sun’. During the presentation, we talk about the Sun, its composition and its features. So we have also the opportunity to remark on an important concept: the difference between stars and planets. We then focus on the Sun as a source of light and introduce the concepts of the source’s power and intensity of light.

In the practical activity students, working in a group, set and solve the proportions they need to make a model of the Solar System on a given scale. Then they use a lamp to illuminate the planets and, with a luxmeter or a smartphone, they take measurements of luminosity intensity at the distance of each planet. The use of a lamp as a source, representative of the Sun, allow us to introduce the concept of a model in physics. The data are collected in a table and can be used to make a graph of intensity versus distance (figure 2).

Students notice that the luminosity intensity decreases with the distance, and that this decrease is larger than in the case of simple inverse proportionality between intensity and distance. They are typically not able to recognise the real type of proportionality. In this second lesson, we also introduced the concepts of habitability zone and the birth of life as we know it today as the related ‘argument of interest’.

4.3. Third activity
The third exercise is on ‘Planetary transit’. The practical work is the simulation of a planetary transit: a black disc passes in front of a lamp in several positions at the same distance from the source and students take measurements of the intensity of light. So intensity values are registered when the ‘planet’ is in different positions relative to the ‘Sun’ and every position is associated with a time instant. In the graph, the time is measured in hours to obtain a light curve similar to a real one. Students use discs of different diameter to simulate different dimensions of the planet.
Figure 2. ‘Planet’ positions referring to the ‘Sun’ and the graph of the registered luminosity at the distance of the different planets.

The activity allows us to emphasize the difference between stars and planets and to introduce the concept of transit, eclipse and occultation. From the mathematical point of view, students can improve the use of a spreadsheet to build a table and a graph. They can note the different depth of the minimum in the light curve and connect this difference to the dimension of the obscuring body (figure 3). The related subject of interest is the KEPLER mission and the discovery of extra-solar planets.

5. Technical school student activities

The students in this type of school usually do not go to the University, and the study of physics is reduced to a few hours for a week and only during the first year. These students are at the beginning of a new scholastic cycle, coming from different first level schools. It is crucial that they work in a group to obtain class relationships; moreover, the teacher is interested to know the mathematical preparation of the students. The practical activity can help to reach both these results.

Figure 3. The curve of light for two different ‘planets’.
With the secondary school students (aged 14–15 years) we propose the activity of ‘The Sun’ and the activity on ‘Meteorites’. In the activity of ‘The Sun’, we proposed the same actions that we proposed to the students of the junior high school. So we present only the second activity.

5.1. Meteorites
The purpose of the activity ‘Meteorites’ is the determination of density through two distinct actions: the measurement of the mass with a scale, and the determination of the volume through the variation of the water’s level in a beaker, when the students immerse the object. For the experimental part, we used stones because we do not have real meteorites. First of all the students measure the diameter of the beaker, then the level of water before and after the immersion of the stone. In this way they can calculate the volume of the displaced water that is also the volume of the stone. Finally, they can calculate the density.

There are many aims associated with this activity: from the physical point of view, it is possible to notice the difference between mass and weight and how we can obtain the density of an object with no geometrical shape. From the mathematical point of view, this can be an exciting way to study how the result of a fraction changes when we modify the numerator or the denominator of the fraction. Students can work with stones of different mass or different volume and calculate their density. As a related appealing subject we show that the different densities of the meteorites imply different compositions, and that this information allows us to know more about the birth of the Solar System.

6. The tests
As stated previously, before and after each activity the students were asked to answer some questions. We analysed the number of correct answers and the distribution of the wrong answers for every class. We present in table 1 an example of this type of organisation of the data (A, B, C, D indicates the different courses of the junior high school for 13-to-14-year-old students).

**Table 1.** Question on habitability zone for 13-14 years old students.

| In the habitability zone of all the stars with a planetary system there is: | A | B | C | D |
|---|---|---|---|---|
| - one planet maximum | 20 | 21 | 19 | 20 |
| - one planet minimum | 12 | 15 | 6 | 10 |
| - it is possible there is no planet | 8 | 6 | 13 | 10 |

To obtain statistical information, we believe that it is better not to separate the results of the different group of students; so in tables 2–5 we report, for some questions proposed after the activity, only the percentage of correct answers.

As an example of physical concept reached, we can see the question on habitability zone (table 1 and table 2). It is an argument not known before the project. Fifty-seven percent of students in the professional school give the right answers, and 54% of students in the junior high school. For the junior high school students, we also consider a question on the interpretation of the light curve (table 3). In this case, 79% of the answers are correct: the students show they understand the difference between stars and planets as a source of light. Some researches show that a lot of people do not know this concept very well.
Table 2. Question on habitability zone for 14-to-15-year-old students.

| A star with luminosity higher than the Sun’s luminosity has a habitability zone: |  |
| --- | --- |
| - closer to the star than the Sun’s |  |
| - at the same distance from the star as the Sun’s |  |
| - more distant from the star than the Sun’s |  |

| Number of students | 60 |
| Number of correct answers | 34 (57%) |
| Number of incorrect answers | 26 (43%) |
| - closer to the star than the Sun’s | 9 (15%) |
| - at the same distance from the star as the Sun’s | 17 (28%) |

Table 3. Question on the effect of planetary transit for 13-to-14-year-old students.

| How is it possible to compare the dimension of two planets, rotating around a faraway star, only measuring the light intensity by a space telescope? |  |
| --- | --- |
| - If the planet is larger, the received light intensity is smaller |  |
| - If the planet is larger, the received light intensity is bigger |  |
| - It is not possible |  |

| Number of students | 80 |
| Number of correct answers | 63 (79%) |
| Number of incorrect answers | 17 (21%) |
| - If the planet is larger, the light intensity is smaller | 11 (13%) |
| - It is not possible | 6 (8%) |

Table 4. Question on density for 14-to-15-year-old students.

| You have two objects with the same volume, and mass A is bigger than mass B. What do you say about density? |  |
| --- | --- |
| - The density of A is greater than the density of B |  |
| - The density of A is less than the density of B |  |
| - The density of A is equal to the density of B |  |
| - It is not possible to say anything |  |

| Number of students | 80 |
| Number of correct answers | 33 (41%) |
| Number of incorrect answers | 47 (59%) |
| - The density of A is less than the density of B | 12 (15%) |
| - The density of A is equal to the density of B | 33 (41%) |
| - It is not possible to say anything | 2 (3%) |

If we consider the question of density (table 4), we note that the percentage of correct answers is only 41%. Even after the activity, in which they worked on density, the students are not able to compare the theoretical density of two objects correctly.

In conclusion, we note that after the activity many students do not use the mathematical tools properly; they have often understood the physical concept, but they are not able to reach the mathematical aims correctly. They need a discussion of the results after the activity that not always was possible.

7. Conclusion
Many students do not like mathematics, but a significant part of them are fascinated by astronomy. For this reason we decided to use astronomical topics in some laboratory activities, in which students have to apply mathematical and physical concepts. We promoted laboratory activities because these help the
comprehension of the concepts. We performed the project with four classes of the junior high school, aged 13 to 14 years, and four of a technical school, ages 14 to 15 years. This choice is related to the content of the science syllabus for these courses.

Each activity is based upon one astronomical topic. The structure of the lesson consists of a brief theoretical presentation of the subject, the preparation and execution of the practical activity, the construction of tables and graphs with the experimental results and the discussion. Some questions are given to the students before and after each laboratory to test the knowledge before and the comprehension of the topic after the activity and the capability of using the related mathematical tools.

After all the activities we asked the teachers their ideas on the project. From their answers, we can say that there is a very positive consideration. Mainly they noted that:

- the activities increased students’ interest in the topics chosen
- students with difficulties appreciated the practical activities
- direct observation of phenomena helps theoretical study

The teachers, and also the results of the post-test, indicate that students need more time to achieve the concepts explained during the activities, so extra time in class is required to pick up all the information and obtain the hoped advantages in mathematical knowledge.

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