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(Article begins on next page)

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The time in science: an interdisciplinary laboratorial approach

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Abstract. In order to promote problem-based and active learning in the physics laboratory, we designed a flipped classroom focused on the Franck-Hertz experiment. The flipped classroom approach moves course content from the classroom to homework and uses class time for engaging activities and problem solving. This constructivist approach to teaching is an effective means of student-centred collaboration and it can promote active learning, enhance critical thinking and obtain the maximum use of student-faculty time together. We report preliminary results of the flipped classroom approach to a laboratory and how it worked in the context of a small group of students in a physics course.

1. Introduction

How to prepare and implement an effective in-service teacher training program to promote teachers' professional development? Despite many actions promoted by national and local administrators in order to enhance the quality of science education in the secondary school, the more effective experiences inspired by science education research remain isolated and find it hard to spread into the classroom practice.

Motivation and interest may facilitate the learning process by increasing student involvement in both laboratory and class discussions [1]. The relationship between interest, motivation and learning process is widely investigated in educational research [2, 3]. In our experience in pre-service and in-service teacher professional development, motivation strategies are relevant and can foster best practices in the classroom.

In order to promote effective methodologies and learning paths inspired by science educational research in the classroom practice in secondary school, we design a national summer school for science teachers. Professional development can provide the opportunities for teachers to learn what they need to know and be able to do as they assist students in the learning process [4]. Active learning, problem-based learning, collaborative learning and inquiry-based teaching strategies could have a significant impact on science education [5-7] if teachers used them diffusely. Moreover, in-service teachers have few opportunities of trying and fully acquiring these educational tools in a laboratory environment.

The summer school was entitled Science in 4D and was designed in such a way that participants were involved in laboratory where they could experience firsthand the effectiveness of these methods in a

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disciplinary or interdisciplinary context. Since motivation has been recognized as an important factor in the construction of knowledge and the process of conceptual change [1] an interdisciplinary approach was pursued in summer school. All activities were focused on the time and its role in the scientific description of natural phenomena.

In the next section, we report the designing of the summer school and list the interdisciplinary laboratories that were proposed to participants. In the following section, some activities are described in more details reporting their effectiveness with students during a physics summer school for selected high school students. In the last section, some comments and remarks on the laboratory approach are given.

2. Hidden harmonies: the time in science

Since in our experience in pre-service teachers training and in orienting student toward science, the most interesting and effective teaching/learning processes often involve an interdisciplinary approach, we decided to propose a school whose participants could be any science teacher (i.e. mathematics or physics, chemistry or science teacher in a secondary school). The focus of the school is to design learning paths centered on a laboratory. Participants qualified in teaching different matters worked together every time it is possible. This way of forming teachers is very different from their initial or in service formation, where usually they are in homogenous working groups.

2.1. The choice of contents

A teacher needs to have a deep understanding of scientific processes in order to guide learners in formulating an investigation question and planning the investigation, as well as a deep understanding of science concepts. For this reason, each edition of the summer school was focused on a relevant topic in science that was declined in a different and significant way for every scientific discipline. The unifying theme proposed is broadly speaking a fourth dimension (beyond 3D in physical space) where a scientific description of nature is realized. Hence, the general title of the summer school became *Science in 4D*. In the first edition in 2016, the transversal theme was the time (*Hidden harmonies: the time in science*), matching the general title with the correct description of nature in physics, i.e. in space-time.

2.2. Method

We pursued professional development with three different actions: plenary lessons, disciplinary and interdisciplinary laboratories, lab sharing in a final plenary session. Let us give more details for the edition focused on time.

For every discipline, we proposed two seminars on the importance of time and how it is used or measured. There was always at least one deepening linked to the latest research or technological applications for enhancing interest in participants, such as molecular clocks for studying evolution or circadian and circannual rhythms, oscillating reactions and chemical clocks, temporal and scalar symmetries in music, Global Positioning System and the space-time of Einstein, time and the alteration of stones in monuments. The lessons were held in a plenary session and affordable to all teachers whatever was their degree or teacher's qualification.

In addition to a deep understanding of science processes and concepts, the effectiveness of inquiry-based instruction increase if teachers engage themselves in inquiry-based approaches as learners. Thus, many laboratories were proposed (the complete list is given in Table 1). All laboratories faced an interdisciplinary issue and, in some case, they were carried out with teachers of different subjects.

In the first lab, teachers were divided into small heterogeneous groups that remains the same for all school. Each group had the final task of choosing one lab to discuss in the final plenary session with all other teachers.

Table 1. The laboratorial activities in the summer school *Hidden Harmonies: The Time in Science*. The initial laboratory was focused on problem solving and lasted for 3 hours. In the following labs, the activities were realized in 2 hours, with the exception of outdoors labs.

<table>
<tr><th>Mathematics and Physics
(upper secondary school)</th><th>Science and Chemistry
(upper secondary school)</th><th>Mathematics and Science
(lower secondary school)</th></tr>
<tr><td colspan="3">A moment or an eternity: estimates and measures of uncommon times
(Lab problem solving)</td></tr>
<tr><td>Function and modelling
(MATH/PHYS)</td><td>The cell cycle (BIO/CHEM)</td><td>The time in the growth of living organisms
(BIO/ PHYS /MATH)</td></tr>
<tr><td colspan="2">Sound and resonance
(PHYS/BIO)</td><td>Strange clocks and surroundings
(MATH/ PHYS)</td></tr>
<tr><td>From the Galileo's pendulum to the pendulum of Huygens
(PHYS/MATH)</td><td rowspan="2">Outdoors Laboratory
(GEO/BIO/CHEM)
Reconstruction of an urban medieval garden and surroundings</td><td>Time in chemical reactions and phase transitions (CHEM/ PHYS)</td></tr>
<tr><td>Maps of space-time
(MATH/ PHYS)</td><td>The alteration of stones
(GEO/CHEM)</td></tr>
<tr><td rowspan="2">Outdoors Laboratory
Measures of times in Astrophysics
(PHYS /MATH)</td><td>Origin and evolution of the eukaryotic cell
(BIO/GEO)</td><td rowspan="2">Outdoors Laboratory
(GEO/BIO/CHEM)
Botanical garden and observation of stones' alterations in the historical centre</td></tr>
<tr><td>Measuring the speed of a chemical reaction
(CHEM/ PHYS)</td></tr>
</table>

Most of laboratories involve physics modelling and measurements. Some of them were designed in a pre-service course and tested with high school students, and others were proposed and discussed with teachers without testing them in a previous pilot.

3. Examples of interdisciplinary laboratories

The laboratories were the most challenging and successful activity in the summer school. The challenge arose from the few time available, but the full engagement of participants and their curiosity and skills in exploring new issues allowed to overcome this problem. They were able to perform more or less all the proposed activities. Moreover, participants and researchers were involved in many interesting discussions on the proposed educational methodologies and their effectiveness in classroom. In the following, few examples are shown emphasizing when they were also tested with high school students mainly in a physics summer school [8, 9].

3.1. A moment or an eternity: estimates and measures of uncommon times

A problem solving lab for estimating or designing measures of uncommon times was proposed in a plenary lab. After a brief introduction to different ways of time measurement and few examples were showed (see figure 1 for a very short time and a very long time), participants were divided into small homogeneous groups with the aim to project how to discuss, estimates or measures a given time in a class.

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Figure 1. On the left, the flight of a hummingbird among flowers. The wing beating of a hummingbird is a very short time that requires special techniques like particle image velocimetry [10]. The pitch drop experiment is shown on the left. In this case, a time-lapse technique can be used for showing the slow dripping [11].

Some examples of the tasks proposed to participants were:

- How can you measure the age of a tree?
- How do you determine the age of a planet? What measures can you do? What assumptions are necessary?
- How could you measure the bloom time of a flower?
- How can you determine the rate of fall of a snowflake? And a drop of water? Of a hailstone? What assumptions for performing the measure and what materials are needed? What activities could be done to justify the hypothesis?
- How can you measure the duration of a lash of eyelashes? Is it achievable in the lab? What materials are needed? How do you measure the frequency of the beating of an insect wing? Can you measure it in a lab?
- For nearly 100 years, an experiment is in progress to measure the viscosity of a liquid by measuring the dripping speed in the gravity range. The experiment in question uses the pitch. If the asphalt or the glass was used how the experimental issues would change? How can the experiment be done? What practical problems can be encountered?

A similar activity was proposed in a physics summer school for high school students. Both laboratories engaged very well the participants but the proposed solutions were often very different. Usually, students had less knowledge about technical aspects and poorly argued, but they were more creative. Fostering the research process of the significant experimental aspects of the proposed problems and of the search for solutions has been very different in the two cases due to the different cultural background.

3.2. Pendulum: from Galileo to Huygens

The laboratory activity on pendulum was designed for mathematics and physics teachers. A learning path focused on the construction and characterization of a cycloid function by using an open source software, *GeoGebra* [12] was the starting point for a discussion about how to construct a cycloid profile and how to study quantitatively the period of Galileo's and Huygens' pendulum by using video analyses techniques [13]. Thereafter, teachers divided in small groups realized a laboratory related to the learning path. A group realized a water clock following Galileo, another compared the motion in gravity field on an inclined plane and a cycloid profile. The isochronism of both pendulums was studied by using an open source software, i.e. *Tracker*. In Figure 2 it is shown the data analysis for the same activity realized in a pilot with high school students and another by teachers in their initial formation.

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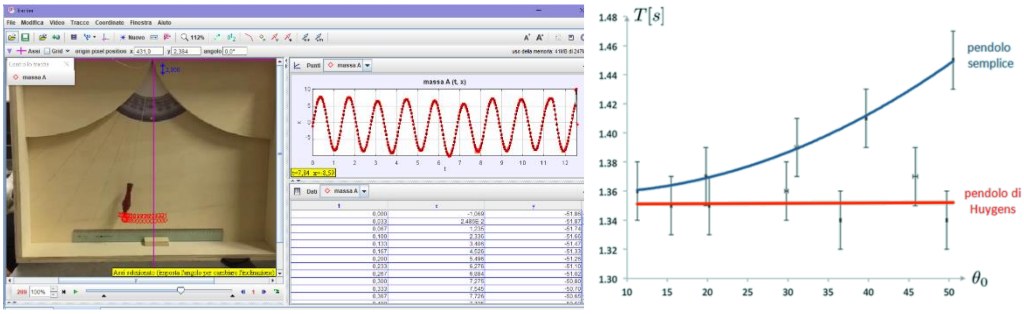

Figure 2. Video analysis of the motion of a pendulum performed with Tracker realized by a group of high school students in an optional laboratory (on the left). Measures of the period for a pendulum of Galileo (blue) and of Huygens (red) realized by teachers in a pre-service course (on the right).

3.3. Sound and resonance
Resonance is a fascinating phenomenon that allows the transformation of energy in a different physical system with negligible thermal dissipation. A learning path on sound was presented for understanding the relevance of resonance in the production and detection of sounds in our body [15]. A teachers' group explored resonance qualitatively by searching the resonant frequencies through the Chladni figures (nodal patterns) in a vibrating metal plate forced by an oscillating force (Figure 3).

Figure 3. Two different Chaldni figures are shown. The visualisation of the nodal patterns is obtained by putting some salt on a metal plate that is forced to oscillate with a fixed frequency. The resonance is easily recognizable by observing the movement of the salt which quickly concentrates in the nodal lines when the frequency corresponds to a normal mode of the vibrating plate.

Another one proposed to teachers was to determine the characteristic time of a ceramic cylindrical magnet hanging from a spring. The magnet was in an oscillating magnetic field generated by a solenoid. Changing the frequency of the magnetic field allows searching for the resonant frequency. In Figure 4, the experimental device is shown in laboratory during a physics summer school for students. Moreover, the students measured the period of the hanging magnet directly and compared the corresponding frequency with the one determined by resonance.

Finally, the others groups explored the sounds emitted by some resonant systems (diapason with a sound box) and the human phonatory system by recording sounds with an open source sound editor [15].

3.4. Measuring the speed of a chemical reaction measuring the speed of a chemical Reaction
Two different reactions are considered, one that gives a linear dependence on time and another that allows studying an exponential relationship.

The reaction between calcium carbonate (marble Ca_2CO_3) and hydrochloric acid (HCl) depends on the contact surface between a solid and the surrounding liquid. The products of this reaction are water, calcium chloride and a gas, carbon dioxide. The missing mass vs. time allowed to determine the speed of the reaction (see Figure 5). An interdisciplinary learning path focused on this laboratory was tested previously in a vocational school with good results. A group discussed the educational aspects and the effectiveness of the laboratory.

Figure 4. The magnet hanging from a spring and the solenoid in laboratory (on the left) and during the physics summer school for students (on the right).

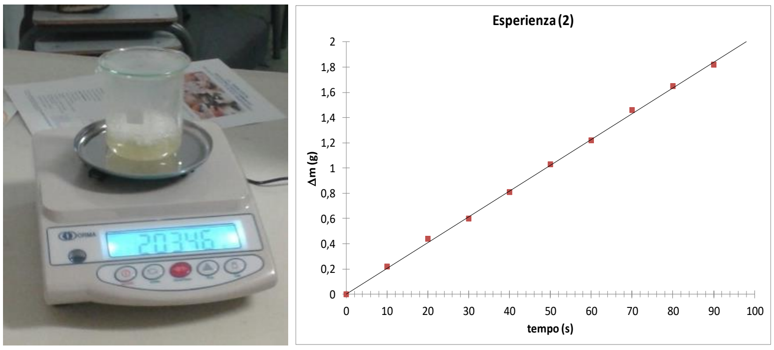

Figure 5. The mass was monitored during the reaction (on the left) in order to measure the missing mass vs. time (on the right).

In the beginning, both compounds are transparent, but when mixed they form a yellow precipitate – solid sulphur. The rate at which the solution turns cloudy allows measuring the speed at which the two compounds are reacting with each other. In the laboratory, a laser beam passed through a flask where the reaction was occurring and hit a photodiode that allows the intensity of the incident light to be measured (see Figure 6). The signal was displayed on the screen of an oscilloscope, showing an exponential decay.

Figure 6. The experimental set-up for the reaction between sodium thiosulphate and hydrochloric acid (on the left) and teachers that analyse the data on the oscilloscope in order to determine the characteristic time of the reaction.

3.5. The time in the growth of living organisms

Finally, let us give some examples of activities that link concepts of biology, physics and mathematics. The focus was on measuring some aspects of the growth of living organisms. The first activity was dedicated to measuring the area of leaves from different vegetal species in order to determine which one is more indicated to introduce to the concept of measurement uncertainty. Then, teachers discussed how can estimate the green biomass of a vegetable at different ages.

Another group examined an herbaceous plant for measuring the size of the leaves in various stages of growth. Participants were able to observe a linear dependence on growth (link with direct proportionality for middle schools and the possibility for high schools of explaining an exponential growth for green biomass).

Finally, other types of growth were examined for focusing that this behaviour is not universal. In other living organisms, like animals or human, different functions better describe the growing.

4. Remarks and conclusions

The summer school encountered widespread interest in teachers throughout the country. We had about sixty requests of participation, and we were able to admit 42 teachers. Among the participants, there were young teachers but also expert teachers close to retirement. Despite very dense and challenging scheduled activities, all teachers responded with great enthusiasm by engaging fully. The most common comment, widely reported in the final questionnaires, was the wonder of how many interesting things could be done in laboratories. Altogether, the capacity to encourage anactive attitude in the laboratories was fully satisfied.

4.1. Beyond the summer school

Some activities inspired by the school entered in common practice or became the starting point for developing learning paths to be used in the ordinary didactics at school. Especially young teachers are more active in this direction.

Some activities inspired by the school entered in common practice or became the starting point for developing learning paths to be used in the ordinary didactics at school. Especially young teachers are more active in this direction.

Moreover, we invited some of them, living not too far, to realize some laboratories in a summer school of physics designed for orienting students toward physics. Many teachers remained in touch throughout social media (e-mail, Facebook) and participated in following editions of the school.

5. Acknowledgements

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