Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Physics of the Earth system: design and implementation of an experimental educational module for high school students

Physics of the Earth system: design and implementation of an experimental educational module for high school students

Marina SERIO, Lodovico BARBERIS, Daniela MAROCCHI and Marta RINAUDO
Department of Physics, University of Turin, Italy

Abstract. This project, specifically designed for high school teaching purposes, is aimed at exploring the physical processes underlying the atmospheric phenomena and includes several important physical concepts. The project was proposed in two versions. The first one involved 5 high school students at the end of the fourth year, participating to a one-week summer internship at the Physics Department in Turin. Four topics related to physics of atmosphere were chosen and for each topic we developed a preliminary test, a theoretical introduction followed by mathematical exercises and lab experiments. Subsequently, the project was proposed to nine first classes of the catering institute "J.B. Beccari" in Turin. These students had never approached a Physics subject before, so the goal was dual: to teach the key concepts of the atmospheric phenomena, and to show that Physics' task is to observe and describe, also in a mathematical language, physical events that occur in everyday life. The results of the post-test indicate an improvement of knowledge on the greenhouse effect. Furthermore, 82% of students consider that the laboratory experiences were stimulating and clarifying, and 62% find some environmental problems to be clearer than before.

1. Introduction

Disciplines such as Environmental Physics and Geophysics have gained large importance in the last decades, as the consequences of the impact these phenomena have on human life and activities. In this field, the cultural formation of an individual greatly influences the choices every citizen is required to make in the democratic life of his or her country.

Another primary objective of teaching is the overcoming of so-called “common-sense belief”, which often prevents the comprehension of the scientific contents and courses of action. Researches in the didactical field are working towards a redefinition of the knowledge. Said redefinition is possible through the individuation of fundamental cores which to connect culturally-significant and fruitful educational trails in a wider interdisciplinary cultural dimension [1].

This project is basically an educational research based on a learning process focused on the physic of atmospheric phenomena. It includes the individuation of theoretical knowledge – required to better understand these phenomena– and of simple lab experiences. These are useful to develop reasoning skills and criticism. We propose this learning process for high school students.

The reason that has driven us to work on this project is the great importance that the atmospheric and environmental themes are gaining in our society. Furthermore, the fact that the physics at the base of these phenomena could be linked with several knowledge fields – such as thermodynamics, heliophysics, chemistry, and even sociological studies – and the desire of transmitting this knowledge to young students prompted this educational activity. In Italy, these topics are usually studied in Earth science courses during the last high school year and, however important, they are not part of the Physics didactic program. In our opinion it is crucial that young people come to possess the most exhaustive point of view possible, in order to overcome misconceptions and develop critical thought.

The objective of this project is to explore these possibilities, both through references to physical topics studied during past school years – i.e. thermodynamic concepts, applied to situations different from the ones typically found in textbooks [2]– and the introduction of new concepts, such as electromagnetic radiation and its interactions with matter. Moreover, we propose the entire work with the aid of experiments carried out without sophisticated instruments. A strong interdisciplinary nature also characterises this project. In fact, the arguments, data analysis through softwares and exercises allow for interaction with Math, IT and Earth science teachers, up to involve themes closer to History and Geography.

Numerous educational experimentations about climatic and environmental topics are present in the scientific literature, so we took them into account during the preparatory phase of the project. The studies we considered agree on the importance of teaching these topics during high school and on the lack of insights during Physics classes. These researches focus their attention on climate change and the overcoming of misconceptions coming from textbooks, newspapers, and everyday speech. Their starting point is a preliminary questionnaire to check the weak points of the students and eventually correct them through a syllabus and mathematical demonstrations [3][4]. In particular, the study carried out by Anikó Tasnádi proposes an interesting pattern: it starts with an introduction about radiation, black body emission, Wein and Stefan-Boltzmann laws, then it proceeds with an energy balance model that includes a mathematical calculation of Earth mean temperature with and without the presence of the atmosphere, and it concludes with some climatic facts.

The learning process here proposed takes the cue from these documents, complementing them with a more realistic model including convective motions, clouds formation, classification and their effect on the energy balance model, basic notions of meteorology and the introduction to climatic and meteorological models. Each part is integrated with experiments in which students can actively participate.

We took the experiments about radiation and the greenhouse effect from previous projects [5][6]. They aimed to clarify the concept of energy, attempting an experimental and educational approach starting from socially relevant themes. In our process, although, the study of the atmosphere, climate and weather become the main focus of the experimentation. For the sake of completeness, we cite another category of studies, aimed to measure the level of knowledge and literacy in post-graduate students through a questionnaire [7][8]. This kind of research is done on a national scale and it is geared to checking the self-efficacy and the civic education of the students. The objective is to lead them to make sustainable choices from an economic, ecologic and social point of view. Our examination starts with a preliminary check of the students' knowledge. Then, it follows a more traditional educational project layout, making use of theoretical lessons and lab experiments. Moreover, the demographic this project is addressed to is significantly smaller compared to these country-wide studies. In fact, our activity was initially intended for a small group of students during a summer internship.

Our project is also aimed at the first classes of a catering school of Turin. The main goal is to increase the interest in Physics, which is studied only during the first school year and it usually does not catch the curiosity of the students. In this case we have to deal with students coming from situations of social vulnerability and sometimes of linguistic and economic disadvantages. Studies carried out in vulnerable communities are already present in the scientific literature, such as the one by S. Lizette Ramos De Robles and Xochitl Barbosa Carmona in Mexico [9]. It aims at lifelong participation and learning about climate change and make use of an exploratory questionnaire to check the previous knowledge of the audience. However, this last project concerns only the climate topic and is aimed to promote science learning in a dairy farmer community – where the average age was 50-60 years – in order to develop strategies to improve production practices and water supplies. Our project wants to give young students a point of view as comprehensive as possible about climate and meteorological studies.

2. Summer Internship

Every year the Physics Department of Turin organises summer internships aimed to high school students. These initiatives fall into the guidance counselling of the university. The internships last a

IOP Conf. Series: Journal of Physics: Conf. Series **1287** (2019) 012017 doi:10.1088/1742-6596/1287/1/012017

work week and are focused on different Physics topics, such as fluid dynamics, thermodynamics and optics. In the year 2017 a project on atmospheric physics was activated for five 11th grade students.

Four theoretical lessons are taught about different topics:

- The concept of radiation and its interaction with matter. This topic, although not directly related to the physics of the atmosphere, is essential to understand the phenomena faced into the next lesson fully.
- Greenhouse effect and the energy balance between Earth, atmosphere and Sun.
- Study of convective motion, atmospheric motion on a global scale; cloud classification and formation.
- Meteorological and climatological models: the reason these models are used and the way they are designed. One of the objectives of this lesson is to present the methodology of researchers working in the field.

Before each lesson, we administer a brief multiple-choice test with a double objective: to encourage the students to self-evaluate their basic skills about the present-day lesson themes and to focus the educational aspect and the didactical methods properly. We evaluate those students simply based on their choices. This way, a possible misconception on technical terminology cannot affect the evaluation. Moreover, one of the questions focuses on a situation close to that observed during the experiment, giving as options plausible predictions of its result.

2.1. Electromagnetic radiation and its interaction with matter

The majority of the atmospheric phenomena occurs thanks to interactions between electromagnetic radiation and the gasses present in the atmosphere. So, we decide to introduce, during the first lesson, the concept of radiation together with electromagnetic waves and their physical quantities. As an introductory argument for the second lesson, we explain the interaction between electromagnetic radiation and matter. By means of absorption and emission, we can define the concepts of black body and its spectrum. In this way the students can better comprehend Wein's law and revise the Stefan-Boltzmann law.

For the experimental part, we propose the study of two metallic tins' temperature – one coated with a black cardstock and the other one with a white cardstock – irradiated with a filament lamp. The first part of the data analysis consists of the graph of the temperature versus time. We ask the students to observe and to comment the trend (see Figure 1). Then, they compare the trends of the two tins, noting in which case they registered the higher temperature and considering whether the obtained result makes sense and why. In order to understand what kind of radiation is emitted from the tins, the students calculate the maximum emission wavelength for each value of temperature with the Wein law, and the maximum power per unit area with the Stefan-Boltzmann law for both tins. Last, they calculate the $\Delta T/\Delta t$ ratio at regular intervals evaluating the slopes of each line segment, in order to use a simple mathematical tool to investigate the temperature variation in time.

IOP Conf. Series: Journal of Physics: Conf. Series **1287** (2019) 012017 doi:10.1088/1742-6596/1287/1/012017

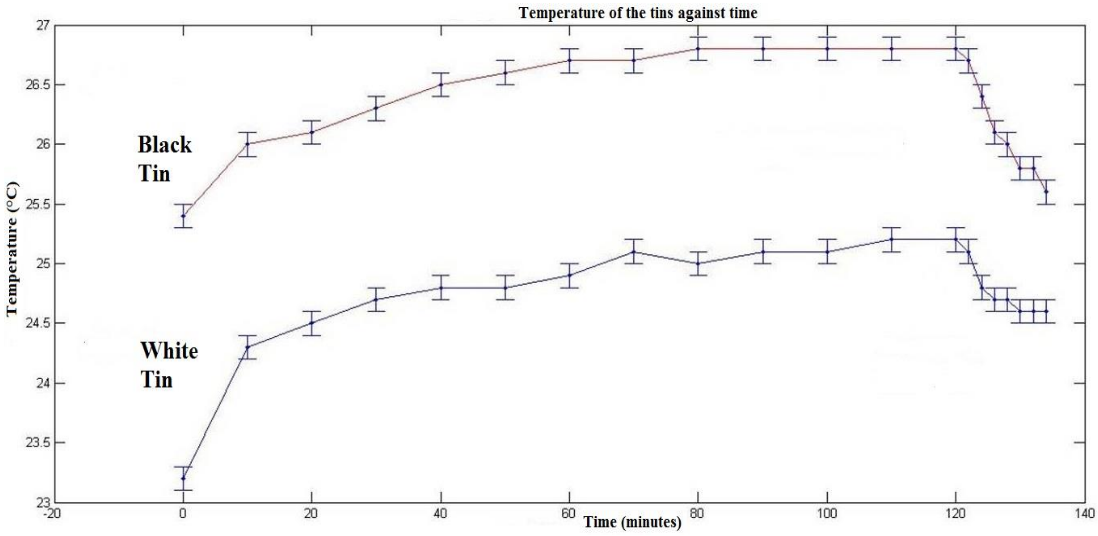
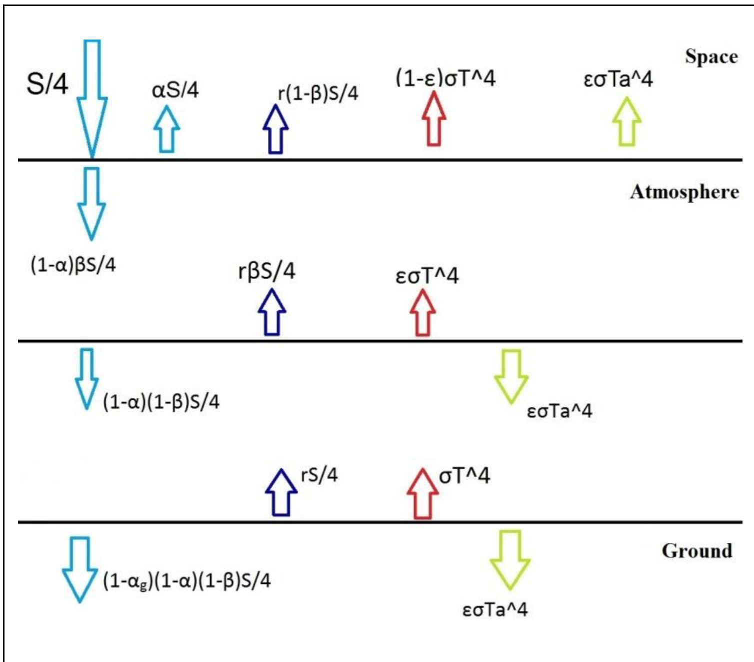


Figure 1. Plot of the temperature versus time for the two tins.

2.2. Greenhouse effect and energy balance model

The second lesson starts with the determination of the solar constant, followed by a first energy balance for the Earth using the SB equation It=σT_e^4, where T_e is the average temperature of the Earth surface. The introduction of albedo then allows the first evaluation of T_e equal to 255 K. This value, significantly lower than the observed one, is therefore associated with the overlooking of atmosphere presence and greenhouse effect. At this point we present a 3-box model. The 3 boxes represent the open space, the atmosphere and the ground. Figure 2 describes a depiction of the model.



S solar constant,
α mean albedo of the clouds,
β absorption coefficient of the atmosphere for the visible light,
ε absorption coefficient of the atmosphere for the infrared light,
T emission temperature of the Earth,
Ta temperature of the atmosphere
r =$(1-\alpha)(1-\beta)\alpha_g$,
$\boldsymbol{\alpha_g}$ albedo of the surface

Figure 2. 3-box model of the atmosphere.

Proceeding with an energy balance for each box, the students can find a value of temperature closer to the one actually observed. In order to achieve this result, they have to observe for each box which quantities are in input and which one is in output with the aid of the arrows shown in Figure 2. In this way, they can write an equation for each box and then put them in a system, as reported in Table 1.

Table 1. “3 boxes” model equations.

Top of atmosphere	$\frac{S}{4} = \alpha\frac{S}{4} + \frac{S}{4}r(1-\beta) + \varepsilon\sigma Ta^4 + (1-\varepsilon)\sigma Ta^4$
Atmosphere	$\frac{S}{4}(1-\alpha)\beta + \frac{S}{4}r\beta + \varepsilon\sigma T^4 = 2\varepsilon\sigma Ta^4$
Ground	$\frac{S}{4}(1-\alpha)(1-\beta) - \frac{S}{4}r + \varepsilon\sigma Ta^4 = \sigma T^4$
Average temperature of Earth surface	$T = \sqrt[4]{\frac{S}{4}\frac{(1-\alpha-r)(2-\beta)}{(2-\varepsilon)\sigma}}$

Students calculate T using mean values for α, β, ε and α_g, (α=30%, β=20%, ε=90%, α_g=4%) obtaining T= 287 K. They then repeat the calculations varying values of parameters in order to understand the weight of each factor in the energy balance of the Earth.

This mathematical model has an experimental realisation aimed at reproducing the greenhouse effect. This allows to observe the variation of temperature from a condition without greenhouse gases to a condition with said gases. In order to achieve this, a black metallic slab is irradiated with a filament lamp. When the temperature of the slab stabilises, we cover it with a transparent plastic lid. The data analysis follows the same steps as in the first lesson: graph of the temperature versus time, the maximum emission wavelength evaluation using the Wein law for each temperature value, the maximum power per unit area of the slab determination through Stefan-Boltzmann law. Last, to have an idea of the temperature variation “intensity”, students evaluate $\Delta T/\Delta t$ ratio at regular intervals .

2.3. Convective motion and cloud formation and classification

The lesson starts with a critical analysis of the limits of the model examined the previous day, which allows the evaluation of an average temperature. Furthermore, chemical and radiative processes for each atmospheric layer, convective motion and evaporation and condensation of water vapour are not considered. Therefore, we discuss convective motions and global atmospheric circulation, followed by the explanation of the physics at the base of cloud formation. The last part is dedicated to the classification and the properties of clouds based on their height and their shape. These topics are relatively new to the students, so we have to neglect wind stress and water movement, Ekman equations, change of wind direction over an obstacle, dew point temperature, pseudo-adiabatic processes and dew point lapse rate, each of which involves advanced physical concepts and mathematical formulae.

In this lesson, we propose two experiments: one aimed to observe a convective motion in a closed-loop tube and the other concerning the reproduction of a cloud in a bottle. For the latter numerous other examples can be found on the web (https://www.youtube.com/watch?v=wagrbfKV5bE). In these two experiments the focus is the observation and description of the phenomena, asking the students to explain the physical aspects involved at the various stages.

2.4. Weather and climate, introduction to modelling

The last part of the project covers the modelling applied in meteorology and climatology. It starts with the differences between weather and climate from the dual point of view of space-time scales typically adopted in these fields of study, together with the kind of studies that defines them. The lesson proceeds to illustrate the main characteristics of meteorological and climatic models and their limits.

During the experimental part, the students analyse temperature, total radiation, relative humidity, wind speed data collected from the meteorological station of the Physics Department in Turin during different years and seasons. The first study concerns annual variation of daily mean values, referred to the months of June, July, August of years 2014, 2015, 2016. The second study examines the seasonal variation, analysing the daily mean values referred to the months of November, December and January 2016-2017. In both cases the students calculate the maximum, minimum and mean values and the standard deviation for each series of measures. They draw a first graph reporting each series of data versus time. Then they draw other graphs reporting for every variable the comparison of values measured at different times, in order to visualise the trends for each year or season. Last, the students speculate about the plots obtained, in order to find a correlation between the involved variables. They find an inverse relationship between temperature and relative humidity, especially during summer. We suggest verifying this correlation with a trend line.

3. Autumn session in the first year of high school

We attempted to propose this educational project as an introductory topic to Physics courses in those educational environments where the subject is taught only during the first school year. This way we could introduce it with topical themes that could result closer to the interest of the students. This part of the project involved 176 students of the first classes of the catering institute “J.B. Beccari” in Turin. It was implemented with the curricular teacher during his class hours.

Since the time granted was shorter – just five sessions of one hour each – and the students involved were going to attend a Physics class for the first time, we decided to reduce and simplify both the topics and the experiments. We also gave more practical examples and caught the interest of the students with topical issues taken from newspaper articles and social network posts, in order to aid them in the learning process. Their knowledge of the laws of physics is quite poor, so we opted to sideline the mathematical formulae and to focus on the scientific stimuli coming from the actual situation in the terrestrial environment.

In this part of the experimentation the goals are several: besides the assimilation of basic concepts about atmospheric physics, the attempt is to increase the interest towards the Physics. To achieve this, we highlight that the purpose of physical studies is to observe and describe events and facts that occur in everyday life, and that it is not an end in itself or a mere mathematical exercise [10][11]. Last, since the addressed topics have a prominent role in our society, this project can also be considered an attempt to improve the school system as a place for civic education.

3.1. Pre-test

At the beginning of each lesson we administer a preliminary test to the students in order to understand the level of their knowledge and organise the lessons more efficiently. Moreover, these tests can activate in the students some cognitive processes, such as memory, comprehension and explanation of their beliefs and opinions.

Since the students never had a Physics class before, the multiple-choice questions are structured so that they can give an answer based on logic or notions that they might have developed during everyday experiences. We avoid questions requiring specific knowledge. The first question is an exception, as it asks to describe the differences between climate and weather. In this case we submit an essay question, because it could be very interesting to analyse the answers given by the students (reported in Table 2). In fact, people often use the two terms as synonyms. Examining the obtained results, it appears that the majority of the students does not know the differences between these two terms. Just an 8% succeeds to give a valid definition.

Table 2. Percentage of answers to the “weather vs climate” question.

What is the difference between climate and weather?	Percentage
Climate indicates the temperature, weather indicates the atmospheric phenomena	51%
The two terms are synonyms	19%
Weather concerns smaller space and time, climate refers to longer times and wider areas	8%
Weather is variable, climate is constant	7%
Weather describes the phenomena and climate the causes of these phenomena	3%
Weather is predictable, climate is not	2%
Did not answer	10%

There are other difficulties in the questions about the greenhouse effect experiment. Some students cannot figure out what will happen to the temperature of the black metallic slab covered with the plastic lid: table 3 reports the results of the choices made by the students. However, 61% of the students prove to understand what happens to the temperature of a black body exposed to a light source.

Table 3. Percentage of answers to the “greenhouse effect” question.

What happens to the temperature of the slab when it is covered with the plastic lid?	Percentage
The temperature would remain the same	28%
The temperature would decrease	20%
The temperature would increase	46%
Did not answer	6%

Last, a lack of knowledge about clouds can be noticed. 49% of the students consider the phrase: “clouds at different height act in different ways in the global warming phenomenon” to be false. This may be due to the fact that these students associate the presence of clouds to bad weather conditions or otherwise to situations where the sunlight is blocked. Nonetheless, they seem to understand the weight of anthropic actions on global warming. Only 24% of students say that mankind had a little or null impact on the environment, against a 73% that supports the fact that humanity had a major influence.

3.2. The final test
At the end of this educational project, the students are tested on the knowledge gained during the lessons. At the end of the test, each student gets a grade, which influences the average final grade. The test consists of 25 multiple-choice questions and it is done on the school computers. We structure the test so that a mnemonic study of the slides projected during the lesson is insufficient to answer all the questions correctly. We want to evaluate if the students did fully understand the explanations, inviting them to reason on the topics of the lessons.

IOP Conf. Series: Journal of Physics: Conf. Series **1287** (2019) 012017 doi:10.1088/1742-6596/1287/1/012017

In order to check the magnitude of the effect the teaching had on the difference between climate and weather, we confront the results obtained during the pre-test and the final test. We calculate the Cohen's *d*, defined as the difference between two means divided by the pooled standard deviation for the data, and the correspondent effect size correlation *r*. The results are reported in Table 4.

Table 4. Effect size of the "weather vs climate" topic.

	Mean score	SD	Number of students	Cohen's *d*	Effect size *r*	Cohen's standard
Pre-test	0.08	0.27	176	1.30	0.55	LARGE
Final test	0.60	0.49	176			

Cohen associated for a value of $d \geq 0.8$ the descriptor "large". "*d*" is a qualitative index of the magnitude of the treatment. The effect size can also be interpreted in terms of the percentage of non-overlapping of the scores of the group before and after the project. For a *d* value equal to 1.30 the correspondent percentage of non-overlapping is 65.3%. We can conclude that the lessons had a significantly positive effect and helped the students to understand the differences between climate and weather.

The question that asks whether the greenhouse effect is a natural phenomenon, already presented during the pre-test, is re-proposed. Previously, only 56% of the students were aware that the greenhouse effect is natural. At the end of the course, the percentage of correct answers rises to 71% against the 29% stating that it is strictly artificial. Table 5 reports the observed frequencies.

In order to verify an actual improvement in this topic after the lessons, we carry out a statistical hypothesis test using contingency tables. A p-value < 0.0037 is obtained. It results to be highly significant, so the null hypothesis must be rejected: the criteria correct/wrong answers and pre/post tests are not independent. This means that the lessons help the students to comprehend better the greenhouse effect is a natural phenomenon.

Table 5. Number of correct and wrong answers during both tests.

	Correct	Wrong
Pre-test	97	76
Final test	125	51

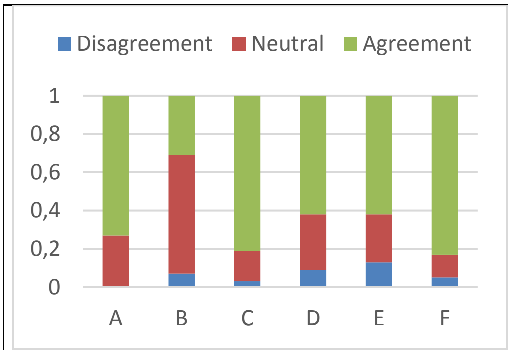
Last, 83% of the students prove to be able to read a graph and to extrapolate the most important information from it. We still detect some difficulties in the questions about the typologies of clouds, with a success rate that does not exceed 30%. However, while the students better understand the physical laws that rule cloud formation, they still find unclear how different types of cloud interact with the different kinds of radiation, and therefore how they get involved in the planetary energy balance.

Other difficulties concern convective motions, with a 32% success rate for the theoretical questions and a 41% success rate for the question about the experimental part. These percentages are even smaller than the one obtained during the pre-test (45%). So it seems that most of the students do not understand this part of the project.

3.3. Impressions on the project

Given that it is the first time these students take an atmospheric physics class, we deem appropriate to check the impression they get from this project about the study of Physics and the quality of the theoretical lessons and the laboratory experiments.

Since it is a short learning project involving classes that never faced an actual physical topic before, the impression these students develop about a topical issue of great interest is as important as the specific knowledge gained during the lessons. In this respect, we propose a satisfaction survey and the results are presented in Figure 3.



A	Studying Physics is something concrete and linked to every day phenomena
B	Theoretical lessons were clear and simple
C	Experiments helped to better understand the concepts explained during theoretical lessons
D	Experiments were simple and easy to reproduce
E	I can better understand the causes of environmental problems
F	Studying a topic that lies outside the classic school program is stimulating

Figure 3. Results of the survey.

From the observed results we can assert that the students understand that the study of physics is not an end to itself, but it is a science concerning the analysis of natural phenomena that regulate everyday life. However, some aspects of the theoretical lessons are too difficult to understand fully, but laboratory activities help a lot in the learning process. Moreover, most of the students find the experiments clear, simple and useful to clarify some concepts.

The second-last question shows that a large majority of the students has a clearer point of view about environmental problems and their causes. Still, there is a percentage that shows some gaps in this topic. From this statistic we can assert that this learning process gave the students many useful tools for debating and gathering information about atmosphere and climate change in a critical way.

Finally, most of the students find stimulating and educational to deal with a topic that lies outside the classic school program. This result can also be taken into consideration for those schools in which Physics classes are only provided during the first years, as in the case of the catering school. We believe that the most important objective for a physics teacher is not to give students notions that they would hardly apply in everyday life, but to shape individuals more aware of the real world and of the society they live in. The present project helps students and teachers in this process, giving space to actuality and to a more socially-oriented study, without forgetting the scientific nature of the topics.

4. Conclusions

The students that attended the summer internship were able to learn several notions in the atmospheric physics field, understanding how these kinds of studies require knowledge in many different branches of learning. They managed to develop a critical point of view based on didactical activities regarding comprehension, application, analysis and evaluation of environmental problems. Moreover, they were able to have a close look at the working method adopted in a scientific experimental environment. This was also achieved through laboratory experiences and data analysis coming from the weather station. This exhorted them to organize what they had learnt during the theoretical lessons, to use these notions in direct observations of physical phenomena and to analyse them. This union allowed the students to understand the modus operandi used by professional figures that operate in this field. We also noticed an improvement in the mastery of technical terminologies and in computer and mathematical languages.

Regarding the catering school, the students learnt not only physical concepts inherent to the atmosphere, but also the processes and fundamental tools of the scientific research: experimental phases, collection and analysis of data and interpretation of a graphic plot. Moreover, these students started to form an idea of what it means to work in a scientific field, understanding that the study of physics has many different applications that influence mankind in its evolution and life.

In this part of the experimental project too, the students could develop a critical thought about the explained topics. In the students' opinion it also appears that in non-optimal conditions – such as hours of lesson, quantity and quality of instructive level of the students – it is possible to raise the interest in more concrete scientific activities, facing topics connected with contemporary problems. Nonetheless, this second part of the project catered to a typology of students that had never addressed a physical topic of this level before, and probably would not have many chances to explore it further, at least in a classic scholastic environment. For this reason, we had to simplify the explained concepts as much as possible. In fact, we tried with the use of computers, the web, interactive tools and examples closer to the everyday lives of the students to activate their cognitive resources and to catch their interest in developing competences that are not part of the initial scholastic project.

5. References

[1] Grimellini Tomasini N, Levrini. O, Casadio C, Clementi M and Medri Senni S 1999 *Insegnare fisica per nuclei fondanti: un esempio riferito al concetto di spazio* La Fisica nella Scuola **XXXII** pp 202-213
[2] Space W 2007 *Climate Physics: Using basic physics concepts to teach about climate change* Science Teacher **74** pp 44-48
[3] Miléř T, Hollan J and Svobodová J 2013 *Climate Change Education for Physics Teachers* ICPE-EPEC 2013 pp 561-569
[4] Tasnádi A 2013 *Climate Models in Physics Lessons* ICPE-EPEC 2013 pp 1065-1072
[5] Besson U, De Ambrosis A and Mascheretti P 2010 *Studying the physical basis of global warming: thermal effetcs of the interaction between radiation and matter and greenhouse effect* Europ. J. Phys. **31** pp 375- 388
[6] Tasquier G 2013 *Cambiamenti Climatici e Insegnamento/Apprendimento della Fisica: una Proposta Didattica* Giornale di Fisica **54** pp 173–193
[7] Uitto A, Boeve-de Pauw J and Saloranta S 2013 *Educational factors explaining 9th graders self-efficacyin ecological sustainable behaviours* Engineer project: breaking new ground in the science educational realm pp 136-143
[8] Kyriazi P. and Mavrikaki E. 2013 *Development of an instrument to measure environmental literacy of post-secondary Greek students – pilot testing and preliminary results* Engineer project: breaking new ground in the science educational realm pp 164-171
[9] Lizette Ramos De Robles S and Barbosa Carmona X 2013 *Climate change literacy for vulnerable communities: a link between school and community* Engineer project: breaking new ground in the science educational realm pp 91-99
[10] Muller R A 2008 *Physics for future Presidents: the Science behind the headlines* Norton&Company N.Y. cap. V
[11] Busch H C 2010 *Using Environmental Science as a Motivational Tool to Teach Physics to Non-science Majors* The Physics Teacher **48** pp 578-58