Quantitative experiments to address change of seasons

Journal:	*Physics Education*
Manuscript ID:	Draft
Manuscript Type:	Paper
Date Submitted by the Author:	n/a
Complete List of Authors:	Testa, Italo; University Federico II, Naples, Department of Physics; Busarello, Gianni; INAF-Astronomical Observatory of Capodimonte, Puddu, Emanuella; INAF-Astronomical Observatory of Capodimonte, Leccia, Silvio; INAF-Astronomical Observatory of Capodimonte, Merluzzi, Paola; INAF-Astronomical Observatory of Capodimonte, Colantonio, Arturo; Liceo Scientifico Medi, Moretti, Maria Ida; INAF-Astronomical Observatory of Capodimonte, Galano, Silvia; University Federico II, Physics Zappia, Alessandro; University Federico II, Physics
Article Keywords:	Seasons, Secondary school, Experiments and lab-work
Abstract:	Literature in science education has shown that students encounter many difficulties in understanding the causes of seasons. Incorrect explanations are often due to a lack of knowledge about the physical mechanisms underlying this phenomenon. To address this issue, we present in this paper a module in which the students are engaged in quantitative measurements with a photovoltaic panel to explain changes of the Sunrays flow on Earth's surface over the year. The activities provide also examples of energy transfers between the incoming radiation and the environment to introduce basic features of Earth climate. The module has been evaluated with 45 secondary school students (17-18 years old) using a pre-post test research design. Analysis of students' learning outcomes supports the effectiveness of the proposed activities.

Quantitative experiments to address change of seasons

1 Introduction

Previous research studies have shown that students encounter many difficulties in understanding the causes of seasons (e.g., Atwood & Atwood, 1996; Baxter, 1989; Sharp, 1996; Trumper, 2000; Nazé & Fontaine, 2014). Most common incorrect explanations range from the naïve idea that when the Earth is closer to Sun it is summer, to more sophisticated, but still incorrect, ideas that the Earth's axis flips back and forth during the motion around the Sun. Other studies have shown that simple qualitative activities are often not effective in addressing the students' intuitive ideas since the physical mechanisms behind this phenomenon remain often hidden (see reviews by Bailey & Slater, 2004; Lelliott & Rollnick, 2010). To address this issue we present in this paper a module in which the students are engaged in quantitative measurements to investigate the factors underlying the change of seasons.

2 Issues in the teaching of the change of seasons

At a qualitative level, seasonal changes are due to two main factors: the inclination of the Earth's axis with respect to the orbit's plane and the revolution of the Earth around the Sun. At a more quantitative level, the tilt of the Earth's axis and the different positions of the Earth result in a different sunrays flow on Earth surface during the year. Actually, students find difficult to relate the "energy" received by the Earth and the different conditions under which Solar light hits the Earth's surface (Galili and Lavrik, 1998). To give students a basic idea of the main physical mechanism underlying the cause of seasons, our module focuses on two key ideas: radiation flow and energy transfers. First, the proposed activities help the students derive the mathematical relationships between the flow across a surface and: (i) the angle between the normal to the surface and the direction of the incident radiation ("cosine" law); (ii) the distance between the surface and a point-like source ("inverse square distance" law). The "cosine" law is a model of how sunrays flow varies at a fixed time of the year over the entire Earth surface leaning towards the Sun; and at a fixed place on the surface as the Earth completes its revolution around the Sun. Similarly, the "inverse square distance" law is a model of the variations of sunrays flow as the distance between the Earth and the Sun changes. Comparing the predictions of the two models, one easily obtains that the tilt of the Earth's axis is predominant with respect to the small eccentricity of the Earth's orbit in the explanation of the change of seasons. Second, the activities provide the students with evidence about the relevance of further factors that affect a given region climate. The aim is to discuss the influence of the length of the day and to elicit the role of water and soil on the environment temperature. In such a way, students are guided to understand that, in principle, both the duration of exposition to the incident radiation and energy transfers between the incoming radiation and the environment affect the temperature of a given location on Earth. Given the complexity of the topic, however, we aimed at simply showing that the energy transfer mainly depends on the environment composition. We hence propose an activity focused on the measurement of the specific heat of the sand relative to water. In such a way, students may justify how the presence of water contributes to the environment temperature with respect to only sand or soil.

3 Activities of the module "Cause of seasons"

The module is divided into four activities, described in the following paragraphs. Table 1 reports an overview of the module.

3.1 Introductory activity

In this activity the students, in small groups, are first asked to define what is a season and identify the main factors underlying change of seasons. Then, the students are asked to design a simple experiment, using a list of available materials, to show the role of the identified factors on the change of seasons. The aim is to investigate whether the students relate the identified factors with physical quantities that can be measured. The activity ends with a class discussion in which the students are guided to select two main factors for seasonal change, namely the inclination of the

Earth's axis and the distance between Earth and the Sun. Moreover, the students are asked to indicate the effects of the absence of the identified factors. The sunrays radiation flow is introduced as a quantity which is measurable by means of a light sensor and that can change according to how the radiation impinges on the given surface and to how far the light source is placed with respect to the surface.

Table 1: Overview of the module "Cause of seasons"

Activity	Time (hours)	What students do	Intended objectives	Teaching materials
1	2	Discuss about the possible factors underlying the cause of seasons. Design an experiment to show the relevance of the identified factors.	To elicit students' ideas about change of seasons. To reinforce students' skills in choosing control variables in experiments.	**Worksheet 1**: *"Why we experience different seasons?"*
2	3	Measure the output power of a photovoltaic panel illuminated by an incandescent lamp when changing the source-panel distance and the inclination of the panel with respect to the direction of the incoming radiation.	To introduce the cosine and inverse square laws of the incident radiation flow on a surface. To reinforce students' skills in dealing with experimental data fitting procedures.	**Worksheet 2:** *"How the Earth's axis inclination and the distance between the Earth and Sun affect seasons' change?"*
3	2	Estimate the solar radiation flow at different locations of the Earth at a fixed time of the year and at a fixed location of the Earth over the year using the models constructed in the previous activity. Estimate the radiation flow at perihelion and aphelion.	To exploit mathematical models to interpret experimental evidences.	**Worksheet 3:** *"Who influences most between distance and axis inclination?"*
4	3	Measure the specific heat of the sand. Discuss about the role of the environment on the temperature of a given location on Earth's surface.	To relate the temperature of a location with the heat transfers between radiation and the environment.	**Worksheet 4:** *"Why the sand burns during summer?"*

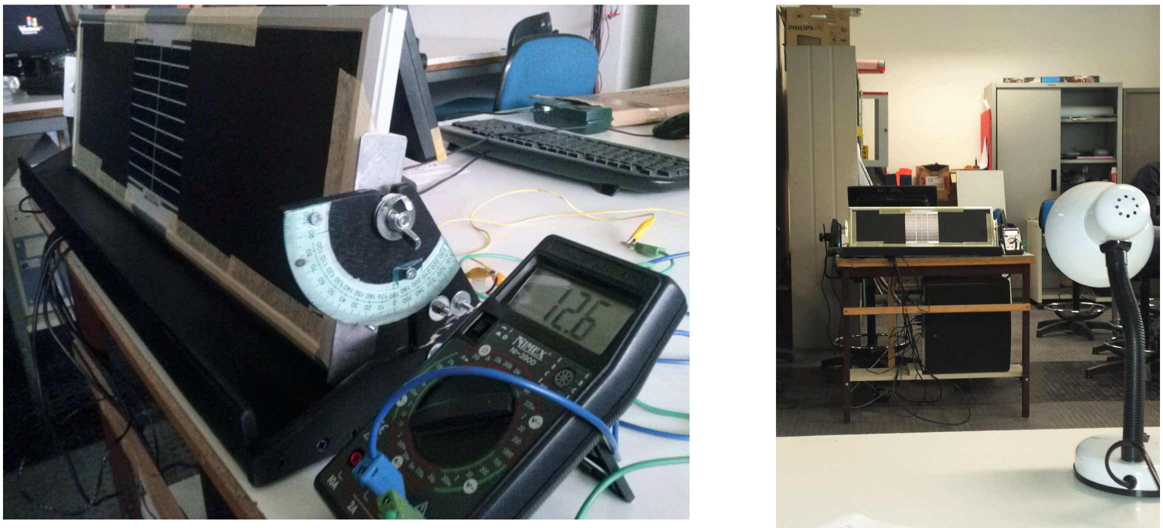
3.2 Experimental activity about the radiation flow

In this core activity of the module, the students quantitatively investigate the dependence of the radiation flow on the inclination between the normal to the incidence surface and the direction of the incident radiation. To this aim, the students, in small groups, are given a photovoltaic panel[1] and an incandescent light bulb (a laboratory "Sun") and are asked to measure the output voltage of the panel as its inclination with respect to a given reference system and its distance from the source change and to calculate the corresponding power dissipated on the panel's load (Fig. 1a and 1b). The relationships between the radiation flow and the cosine of the incident angle and the inverse square distance (equations (1) and (2)) are then experimentally derived by each group by means of a linear fit. In equation (1), the "cosine" law, P_0 is the power received by the panel when the angle θ between the normal to the surface panel and the direction of the incident radiation is 0. In equation (2), the "inverse square distance" law, A is a dimensional constant that takes into account the geometry of the sensible area of the panel and the power emitted by the source. Typical experimental curves are shown in fig. 2 and 3.

[1] During the activity, the panel has been introduced to students as a constant current generator. To ensure that the output power was proportional to the incoming one (linearity interval), resistors of resistance from *0.9 kΩ* to *0.1 kΩ* have been used by the students as loads of the panel.

$$\frac{P(\theta)}{P_0} = \cos(\theta) \quad (1)$$

$$P(D) = \frac{A}{D^2} \quad (2)$$



(a) (b)

Figure 1. experimental setting used for the measurement of the light flow on a solar panel according to (a) the incident angle, (b) the distance between the source and the panel. When the panel is perpendicular to the table, the angle between the normal to the panel and the direction of incident radiation is 0°. Part of the panel surface was covered to meet the requirements for obtaining a radiation flow as similar as possible to that described by equations (1) and (2). The sensible area of the panel is about 200 cm^2, the distance between the light lamp and the center of the panel ranges from 120 to 310 cm.

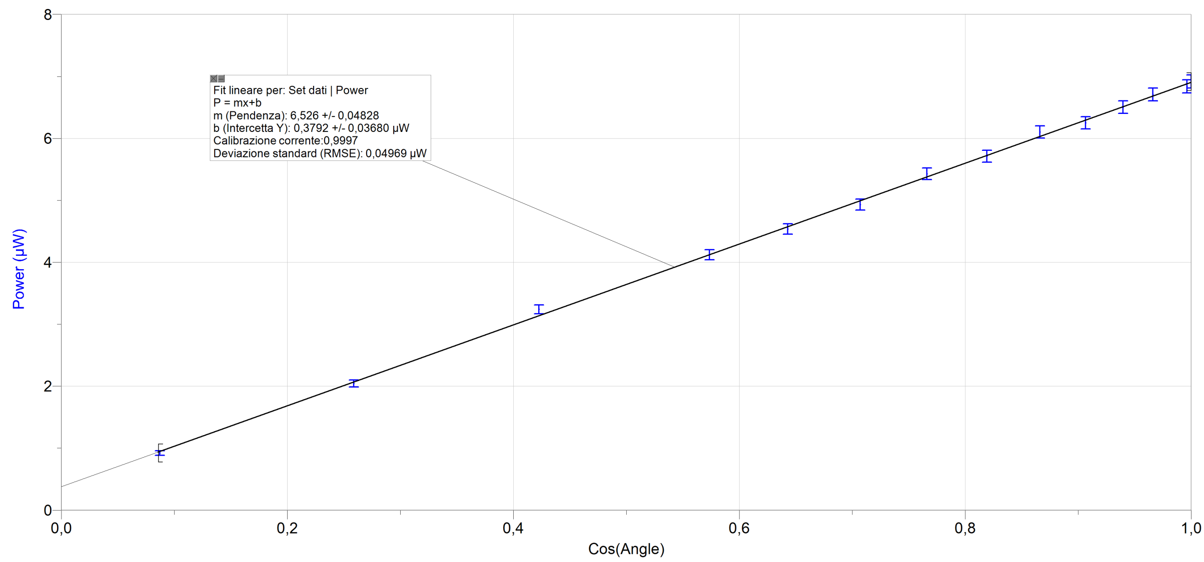


Figure 2. Output power of the panel lighted by a 100W incandescent lamp vs. inclination between the normal to the panel and the direction of the radiation. The fit gives: $P(\theta) = m\cos(\theta) + b$, $m = (6.53 \pm 0.06)\,\mu W; b = (0.38 \pm 0.04)\,\mu W$. The slope represents the output power when the normal to the panel surface is parallel to the direction of the incident radiation, whereas the intercept *b* represents the background radiation, ideally equal to 0.

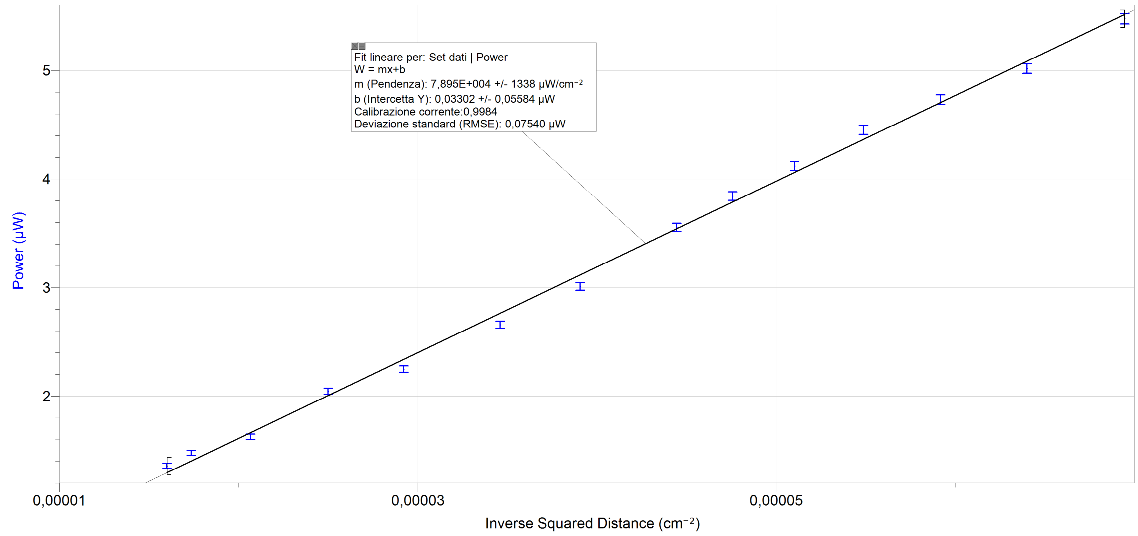


Figure 3. Output power of the panel lighted by a 100W incandescent lamp vs. the distance between the centre of the panel and radiation source. The fit gives: $P(D)=\frac{m}{D^2}+b$ with $m=(7.90\pm 0.13)\,\mu W m^2; b=(0.03\pm 0.06)\,\mu W$. Here the slope represents the output power when the source is at a distance $D=1\,m$ from the panel, whereas the intercept b represents the background radiation, ideally equal to 0.

3.3 Modelling activity

Starting from equations (1) and (2) the students are asked to evaluate the incident radiation flow at a fixed time for five climatic zones: tropics, Equator, polar circles. They use the following equation:

$$1-\frac{P(\theta_w)}{P(\theta_s)}=1-\frac{\cos(\theta_w)}{\cos(\theta_s)} \tag{3}$$

where θ_w and θ_s are the angles formed by the direction of the solar radiation with the normal to the incident surface at the chosen locations at two specific times of the year: winter and summer solstices (tropics and Equator), summer/winter solstices and autumn/spring equinoxes (Arctic and Antarctic circle), respectively.

Hence, using the model of the distance, the students are asked to calculate the normalized difference for a generic place on Earth:

$$1-\frac{P(D_{Aphelion})}{P(D_{Perihelion})}=1-\left(\frac{D_{Perihelion}}{D_{Aphelion}}\right)^2 \tag{4}$$

and to compare the result with that obtained for the five locations of the Earth from equation (3). Using equation (4), it is easy to show that the difference due to the change of the distance, independently on the location on the Earth's surface, could be at maximum 6.5%, which is much less than the differences obtained from (3) (see Table 2-4). In such a way, the distance misconception can be quantitatively addressed. The activity then features a final class discussion to strengthen the students' understanding of the relationships between the changing radiation flow and the motion of the Earth along the orbit and the constant direction in space of the axis.

Table 2 Normalized power received at the tropics and Equator at Summer and Winter solstices at a fixed time. See equation (3) for the calculations

Geographic Zone	Summer Solstice	Winter Solstice	% Difference
Cancer tropic	1,00	0,68	32%
Equator	0,92	0,92	0%
Capricorn tropic	0,68	1,00	32%

Table 3. Normalized power received at the polar circles at Summer (Arctic) and Winter (Antarctic) Solstices and Spring/Autumn equinoxes at a fixed time. See equation (3) for the calculations

Geographic Zone	Solstices	Equinoxes	% Difference
Polar circles	0,73	0,40	55%

Table 4 Normalized power received at a generic location on Earth using aphelion and perihelion distances as the maximum and minimum distances from the sun at a fixed time. See equation (4) for the calculations

Geographic Zone	Maximum Distance	Minimum Distance	% Difference
Generic	0,93	1,00	6,5%

3.4 Specific heat activity

In the fourth, and final activity, the students are guided to elicit their ideas about why Earth's locations at only slightly different latitudes have different average temperatures during the year (a typical Earth map is given to the students). A basic model of thermal interaction is then proposed, focusing in particular on the role of specific heat of involved substances. An experiment that students can design and perform involves the thermal interaction between water and a substance with unknown specific heat. For this activity we chose sea sand in order to recall students' experience with the fact that during summer the sea takes much longer than the sand to become hot. After heating at temperature T_{iwater} a mass m_{water} of water (specific heat $c_{water} = 1\ cal\ g^{-1}°C^{-1}$), the students measure the equilibrium temperature T_e when the water mass is mixed with a mass of sand m_{sand} (of unknown specific heat c_{sand}), initially at temperature $T_{isand} < T_{iwater}$. Hence, using the equilibrium relationship:

$$\frac{c_{sand}}{c_{water}} = \frac{m_{water}\left(T_{iwater} - T_e\right)}{m_{sand}\left(T_e - T_{isand}\right)} \tag{5}$$

they can estimate the ratio $\frac{c_{sand}}{c_{water}}$, which should be around 0.3 - 0.4[2] (Table 5).

Table 5. Estimation of the specific heat of the sand. See equation (5) for the calculations

Water mass (g)	Sand mass (g)	Initial temperature of water (°C)	Initial temperature of sand (°C)	Equilibrium temperature (°C)	Specific heat of sand relative to water (cal/ g °C)
250	150	52,0	21,0	46,6	0,35
190	150	53,0	21,0	45,0	0,44
175	150	50,0	20,0	43,4	0,33
150	150	54,0	21,0	45,0	0,38
220	150	55,0	21,0	48,2	0,37

[2] Teachers can find a table of common substances specific heat at http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html

A typical value of the specific heat of sand relative to water found by students is 0.37 ± 0.06, which is in agreement with the expected value for clay/sand and wet soil.

4 Implementation and evaluation of the module

In the following, we give a brief summary of the sample, the used instrument and students' learning outcomes.

4.1 Sample

The module was implemented with 45 secondary school students (two fifth classes, 17-18 years old) in two South Italy school contexts, for a duration of 12 hours for each implementation. The classes had already addressed some astronomical concepts in their Earth Science school curriculum, including seasons. However, given the differences in the programs of Physics and Sciences subjects (taught by different teachers), astronomical concepts are usually addressed only at a qualitative level without any reference to the underlying physics. Therefore, we chose such sample since we wanted to investigate if the module's experimental activities could improve students' understanding of the addressed concepts.

4.2 Instrument

To investigate students' understanding of the seasonal change, a pre-post test design was adopted. This choice was aimed at investigating the extent to which the modules' activities could improve the students' conceptual understanding of the topic. A written questionnaire (see Appendix) featuring four items about the relevant concepts of the module was submitted to the sample before and after the activities. Each item featured a two-tier structure: three true/false statements and one multiple choice question. The true/false statements concerned basic facts that the students should know to answer the multiple choice question. The multiple choice questions featured a correct statement and three incorrect statements based on previous research studies on students' ideas about cause of seasons (Trumper, 2000). For each correct answer to the true/false statement a score of 0.5 was given, while for a correct answer to a multiple choice question 1 point was given, so that the maximum possible score was 10. The concepts addressed in each of the questionnaire items were related to the factors underlying the cause of seasons discussed during the activities, namely: (i) the motion of the Earth around the sun; (ii) the inclination of the Earth's axis; (iii) its constant direction in space; and (iv) the influence of the environment on the temperature at a given location. Table 6 summarizes the items of the questionnaire.

Table 6: Description of the items of the questionnaire

Questionnaire Item	Factor addressed
1	The varying position of the Earth on its orbit causes a variation in the inclination of the sunrays on Earth's surface.
2	Temperature at a given location is influenced by environment and by the sunrays inclination and length of day.
3	Revolution around the Sun of the Earth and the fact that axis tilt causes a variation of the sunrays inclination on Earth's surface.
4	Since the Earth's axis always points in the same direction, during the motion around the sun, the sunrays have different inclination on Earth's surface during the year.

4.3 Results

Thirty-four students completed both pre- and post-test. Overall, the average score in the pre-test was 5.6 ± 1.5 (st.dev.), while in the post test it was 9.2 ± 0.9 (st.dev.). The average normalized gain (Hake, 1998) was 79.3%, which suggests a large effect of module activities on students' conceptions. Differences in the average score between pre- and post-test are statistically significant (*t* = -*11. 956*, *df* = *33; p* < *10*$^{-4}$). The distribution of students' correct answers to the four items[3] in the pre- and post-test is shown in fig. 4.

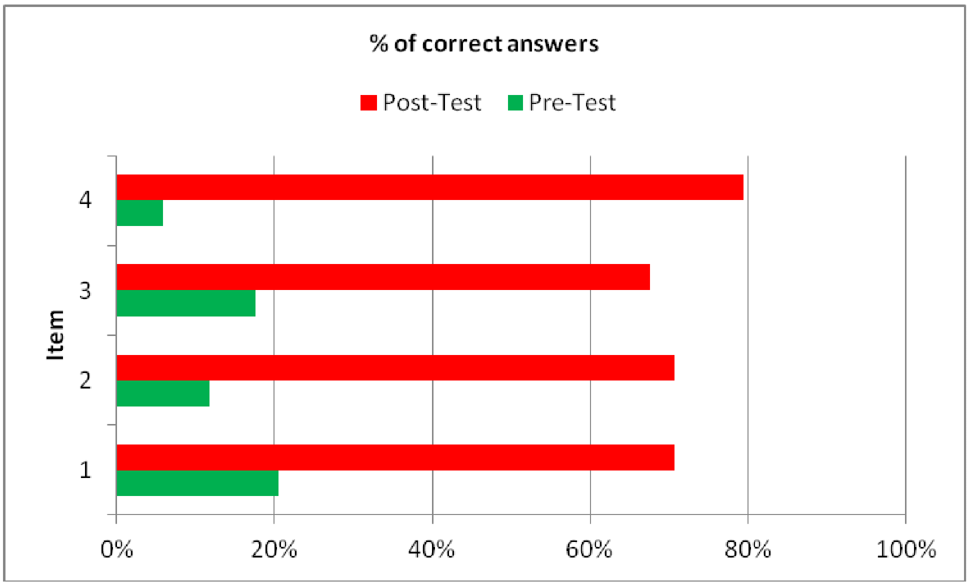


Figure 4. Distribution of students' correct answers for the four items in the pre- and post-test written questionnaire. Refer to Table 6 for items' description.

In the pre-test, students found difficulties especially in recognizing the role of the constant direction in space of the Earth's axis on the change of seasons (6% of correct answers) and in explaining the role of the environment on the temperature at a given location on the Earth (about 12% of correct answers). The tilt of the axis and revolutionary motion around the Sun seem the two factors the students were most familiar with for explaining the cause of seasons (about 20% of correct answers in the corresponding items). However, despite the students in the sample had already addressed the topic in their Earth Science school curriculum, the varying distance between the Sun and the Earth and the changing direction of the Earth's axis emerged in about 40% of the answers as possible factors for the change of seasons. Surprisingly, the idea that the axis of Earth changes direction in space during the orbital motion emerged in about 20% of the answers.
In the post-test, the students improved their performance in all items, especially in the fourth one (about 80% of correct answers). Such evidence suggests that activities' focus on the relationships between the constant direction in space of the Earth's axis and the changing radiation flow on Earth's surface helped the students to abandon naïve reasoning schemes about the cause of seasons centred on the distance misconception and on an Earths' axis which changes its direction in the space. Moreover, the emphasis on the thermal transfers in the fourth activity seems to have increased students' understanding about the basic factors that affect the climate of a region.

5 Conclusions

Students' difficulties in giving correct explanations of the cause of seasons have been widely studied in science education (Sneider, Bar and Kavanagh, 2011). To address such difficulties, researchers in physics education have proposed a variety of qualitative teaching approaches to address such inaccurate explanations (Hughes, 2010; Kücüközer, 2008; Ruangsuwan & Arayathanitkul, 2009; Starakis & Halkia, 2014). In this paper, we propose an innovative module where students are gradually introduced to the basic physics concepts underlying seasons' change through simple but quantitative experiments. The module features also modelling activities to let students construct an interpretation mechanism for their every day experience with the seasons phenomenon. Such activities differ from those proposed in previous studies in that the physical quantities influencing the change of the seasons – namely, radiation flow (power per surface unit)

[3] An answer to an item has been considered correct if the score was the maximum for both true/false questions and multiple choice question

and energy transfers between radiation and environment – are quantitatively measured by the students in simplified situations and then used to construct the models that account for the well known evidences related to the seasons. The cosine and inverse square distance laws are used to show that the effect of the tilt of the axis is greater than that of the change of the Earth – Sun distance on the radiation flow changes. Particular emphasis is put on involving students in discussions, since the beginning, about what could happen if the axis of the Earth was not inclined but perpendicular to the orbit and if the distance between Earth and Sun would be constant. In the same way, the specific heat of the sand with respect to water is used to interpret basic aspects of the energy transfer between the radiation and the substances (soil, water, rocks) present in the environment in the Earth's regions.

Overall, the results of the pre- and post-test questionnaires are encouraging and support the effectiveness of the proposed activities. In particular, the distance misconception and the naïve idea that the Earth's axis may change direction in space seem to have been successfully addressed. We plan to improve the module by strengthening the final activity on climate factors including some more experiments on the interaction between the environment and solar radiation.

Acknowledgements

The work presented in this paper was supported by the Italian Ministry of Education through the **Piano Lauree Scientifiche Project** for the academic year 2013-14. We also kindly thank the **INAF-Astronomical Observatory of Capodimonte**, Naples, for the use of their structures during the implementation of the module with the involved schools.

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Appendix – Questionnaire used in the study[4]

1a. Indicate for each of the following sentences if they are true or false

The sun produces more energy in summer than in winter	T	F
The energy absorbed by a surface illuminated by a light source is maximum when the light strikes the surface perpendicularly	T	F
The incidence of solar radiation on the earth's surface varies throughout the year	T	F

1b. The main reason for which the summer and winter alternate is (please indicate the correct one)

i. The distance between Earth and Sun during the year changes and hence also the incidence on Earth surface of the solar rays varies
ii. The inclination of the Earth' s axis with respect to the orbit plane changes during the year and hence also the incidence on Earth surface of the solar rays varies
iii. The direction of the Earth's axis in space changes during the year, and hence also the incidence on Earth surface of the solar rays varies
iv. The position of the Earth on the orbit changes and hence also the incidence on Earth surface of the solar rays varies

2a. Indicate for each of the following sentences if they are true or false

The Earth surface absorbs energy from the sun	T	F
The temperature of a location on Earth depends on the energy transfers with the environment	T	F
The energy absorbed at a location on Earth depends on the depth of the atmosphere	T	F

2b. Which is the reason for which in Italy during summer it is hotter than in the winter? (please indicate the correct one)

i. During summer the Earth is closer to the Sun and the day is longer than in winter
ii. During summer, the inclination of the Earth's axis is changed
iii. During summer the solar rays are less inclined and the day is longer
iv. During summer the Sun produces more energy

3a. Indicate for each of the following sentences if they are true or false

The axis of rotation of the Earth precedes during the year	T	F
The axis of rotation of the Earth is inclined with respect to the orbit plane	T	F
The axis of rotation of the Earth during the year remains parallel to itself	T	F

3b. Some students answer to a question with the following sentences. Who is right? (please indicate the correct one)

i. The variation of the incidence of the solar rays on the Earth surface during the year is due to the revolution of the Earth around the Sun and the variation of the Earth-Sun distance
ii. The variation of the incidence of the solar rays on the Earth surface during the year is due to the revolution of the Earth around the Sun and the inclination of the Earth's axis with respect to the orbit plane
iii. The variation of the incidence of the solar rays on the Earth surface during the year is due to the inclination of the Earth axis with respect to the orbit plane and to its oscillation
iv. The variation of the incidence of the solar rays on the Earth surface during the year is due to variation of the Earth – Sun distance and to the fact that the axis of rotation of the Earth is normal to the plane of the orbit

4a. Indicate for each of the following sentences if they are true or false

The motion of the Earth around the Sun is a periodic motion around a closed orbit	T	F
The orbit of the Earth around the Sun is an highly eccentric ellipse	T	F
The periodicity of the seasons is related to the revolutionary motion of the Earth around the Sun	T	F

4b. Which of the following sentences better explains the phenomenon of the different seasons? (please indicate the correct one)

i. During the revolutionary motion the Earth-Sun distance changes and, hence, in a given location the solar rays have not always the same incidence on the surface
ii. During the revolutionary motion the Earth axis changes direction and, hence, in a given location the solar rays have not always the same incidence on the surface
iii. During the revolutionary motion the Earth axis remains parallel to itself and, hence, in a given location the solar rays have not always the same incidence on the surface
iv. During the revolutionary motion the Earth axis is always perpendicular to the orbit plane and hence, in a given location the solar rays have not always the same incidence on the surface

[4] Correct answers are indicated in bold face