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Italo Testa[1], Gianni Busarello[2], Emanuella Puddu[2], Silvio Leccia[2], Paola Merluzzi[2], Arturo Colantonio[3], Maria Ida Moretti[2], Silvia Galano[1] and Alessandro Zappia[1]

[1] Department of Physics, University Federico II, Naples, Italy
[2] INAF-Astronomical Observatory of Capodimonte, Naples, Italy
[3] Liceo Scientifico Medi, Cicciano, Naples, Italy

E-mail: italo@na.infn.it

Abstract

The science education literature shows that students have difficulty understanding what causes the seasons. Incorrect explanations are often due to a lack of knowledge about the physical mechanisms underlying this phenomenon. To address this, we present a module in which the students engage in quantitative measurements with a photovoltaic panel to explain changes to the sunray flow on Earth's surface over the year. The activities also provide examples of energy transfers between the incoming radiation and the environment to introduce basic features of Earth's climate. The module was evaluated with 45 secondary school students (aged 17–18) and a pre-/post-test research design. Analysis of students' learning outcomes supports the effectiveness of the proposed activities.

1. Introduction

Previous research studies have shown that students encounter many difficulties in understanding what causes the seasons (e.g. Baxter 1989, Atwood and Atwood 1996, Sharp 1996, Trumper 2000, Nazé and Fontaine 2014). The most common incorrect explanations include the naive idea that when the Earth is closer to the Sun it is summer, and the more sophisticated, but still incorrect, idea that the Earth's axis flips back and forth during its motion around the Sun. Other studies have shown that simple qualitative activities are often ineffective in addressing students' intuitive ideas because the physical mechanisms behind this phenomenon often remain hidden (see reviews by Bailey and Slater 2004, Lelliott and Rollnick 2010). To address this we present a module in which students are engaged in quantitative measurements to investigate the factors underlying the change of seasons.

2. Issues in teaching 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 change the sunray flow on Earth's surface during the year. Students find it difficult to relate the energy received by the Earth to 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 causing the

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Table 1. Overview of the module 'Cause of seasons'.

Activity	Time (h)	What students do	Intended objectives	Teaching materials
1	2	Discuss the possible factors underlying the cause of seasons. Design an experiment to show the relevance of the identified factors.	To elicit students' ideas regarding the change of seasons. To reinforce students' skills in choosing control variables in experiments.	**Worksheet 1**: *Why do we experience different seasons?*
2	3	Measure the output power of a photovoltaic panel illuminated by an incandescent lamp while 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 does the Earth's axis inclination and the distance between the Earth and Sun affect the change of the seasons?*
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 evidence.	**Worksheet 3:** *Which is more relevant, distance or axis inclination?*
4	3	Measure the specific heat of the sand. Discuss the role of the environment on the temperature of a given location on Earth's surface.	To relate the temperature of a location to the heat transfers between radiation and the environment.	**Worksheet 4:** *Why does sand burn during summer?*

seasons our module focuses on two key ideas: radiation flow and energy transfer.

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 sunray flow varies at a fixed time of the year over the entire Earth's 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 sunray flow as the distance between the Earth and Sun changes. Comparing the predictions of the two models, one easily obtains that the tilt of the Earth's axis is more significant than the small eccentricity of the Earth's orbit in explaining the change of seasons.

Second, the activities provide the students with evidence about the relevance of further factors that affect a given region's climate. The aim is to discuss the influence of the length of the day and to examine the role of water and soil in the environmental temperature. In this way, students are brought to understand that, in principle, both the duration of exposure to the incident radiation and the energy transfers between the incoming radiation and the environment affect the temperature of a given location on the Earth. Given the complexity of the topic, however, we simply aimed to show that the energy transfer depends mainly on the environmental 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 understand how the presence of water or soil contributes to environmental temperature.

3. Activities of the 'Cause of seasons' module

The module is divided into four activities, described below. Table 1 gives an overview of the module.

3.1. Introductory activity

In this activity the students, in small groups, are first asked to define what a season is and to identify the main factors underlying the change of

(a) (b)

Figure 1. Experimental setting used for the measurement of the light flow on a solar panel according to (*a*) the incident angle and (*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 obtain a radiation flow as similar as possible to that described by equations (1) and (2). The sensible area of the panel was about 200 cm^2 and the distance between the lamp and the centre of the panel ranged from 120 to 310 cm.

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 in the change of seasons. The aim is to investigate whether the students relate the identified factors to 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 the Earth and Sun. Moreover, the students are asked to indicate the effects of the absence of the identified factors. The solar radiation flow is introduced as a quantity that is measurable by means of a light sensor and that can change according to how the radiation impinges on the given surface and how far the light source is placed with respect to the surface.

3.2. Experimental activity concerning 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. With this aim, the students, in small groups, are given a photovoltaic panel[4] 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 (figures 1(*a*) and (*b*)). The relationship between the radiation flow and both the cosine of the incident angle and the inverse square distance (equations (1) and (2)) is 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 figures 2 and 3.

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

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

[4] During the activity the panel was 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 to 0.1 kΩ were used by the students as the panel loads.

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 conventional locations: the

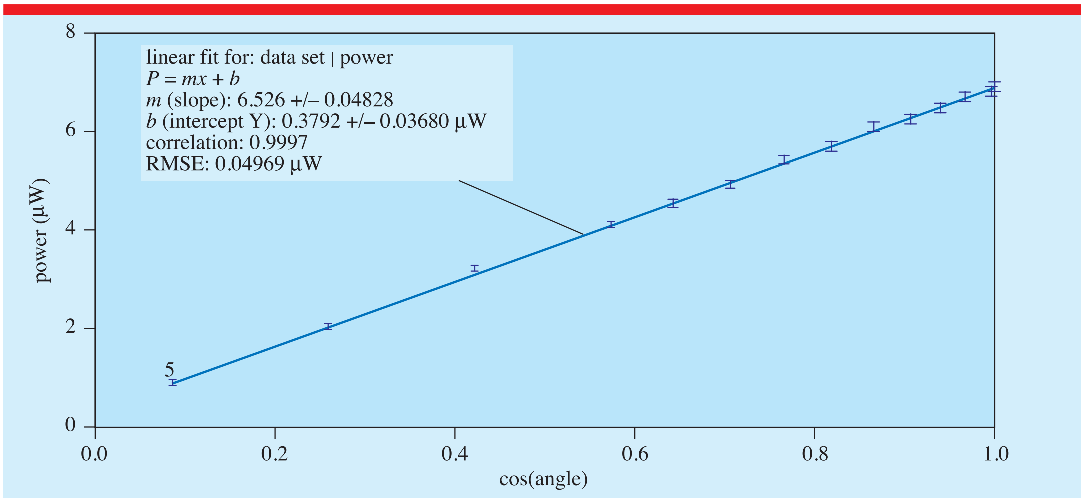

Figure 2. Output power of the panel lit by a 100 W incandescent lamp versus inclination between the normal to the panel and the direction of the radiation. The fit gives: $P(\theta) = m \cos(\theta) + b$, $m = (6.53 \pm 0.05)$ μW; $b = (0.38 \pm 0.04)$ μ W. The slope represents the output power when 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.

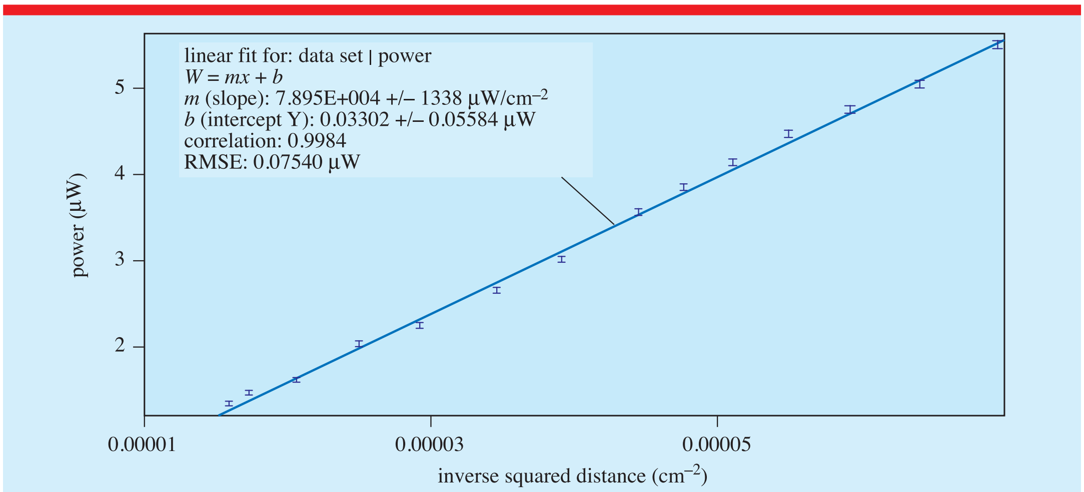

Figure 3. Output power of the panel lit by a 100 W incandescent lamp versus the distance between the centre of the panel and radiation source. The fit gives: $P(D) = m / D^2 + b$ with $m = (7.90 \pm 0.13)$ μWm^2; $b = (0.03 \pm 0.06)$ μ W. Here the slope represents the output power when the source is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

tropics, the equator and the polar circles. They use the following equation:

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

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: the winter and summer solstices (tropics and equator), and the summer/winter solstices and autumn/spring equinoxes (Arctic and Antarctic circle), respectively.

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

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

Table 2. Normalized power received at the tropics and equator during the summer and winter solstices at a fixed time. See equation (3) for the calculations.

Geographic location	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 during the summer (Arctic) and winter (Antarctic) solstices and the spring/autumn equinoxes at a fixed time. See equation (3) for the calculations.

Geographic location	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 location	Maximum distance	Minimum distance	% difference
Generic	0.93	1.00	6.5%

They then compare the result to those 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 can be at most 6.5%, which is much less than the differences obtained from (3) (tables 2–4). In such a way, the distance misconception can be addressed quantitatively. 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 of the axis in space.

3.4. Specific heat activity

The fourth and final activity elicits the students' ideas about why locations at only slightly different latitudes have different average temperatures during the year. (A typical map of the Earth is given to the students.) A basic model of thermal interaction is then proposed, focusing in particular on the role of the specific heat of the substances involved. An experiment about the thermal interaction between water and a substance with unknown specific heat is one that students can design and perform. For this activity we chose sea sand so that we could relate it to the students' experience of the sea taking much longer to become warm than the sand in the summer. After heating at temperature T_{iwater} a mass m_{water} of water (specific heat $c_{\mathrm{water}} = 1\ \mathrm{cal\ g^{-1}\ {}^{\circ}C^{-1}}$), 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 $T_{\mathrm{isand}} < T_{\mathrm{iwater}}$. Hence, using the equilibrium relationship

$$\frac{c_{\mathrm{sand}}}{c_{\mathrm{water}}} = \frac{m_{\mathrm{water}}\,(T_{\mathrm{iwater}} - T_{\mathrm{e}})}{m_{\mathrm{sand}}\,(T_{\mathrm{e}} - T_{\mathrm{isand}})}, \qquad (5)$$

they can estimate the ratio $c_{\mathrm{sand}} / c_{\mathrm{water}}$, which should be around 0.3–0.4[5] (table 5).

A typical value found by the students for the specific heat of sand relative to water 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 instrument used and students' learning outcomes.

4.1. Sample

The module was implemented with 45 high school students (two classes, aged 17–18) in two schools in southern Italy, for 12 h per implementation. The classes had already addressed some astronomical concepts in their earth science school curriculum, including the seasons. However, given the differences between the physics and sciences programmes (taught by different teachers), astronomical concepts are usually only addressed at a qualitative level, without any reference to the underlying physics. Therefore, we chose such a sample because we wanted to investigate if the module's experimental activities

[5] Teachers can find a table of common substances' specific heats at www.engineeringtoolbox.com/specific-heat-capacity-d_391.html.

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^{-1} °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

could improve students' understanding of the concepts addressed.

4.2. Instrument

To investigate students' understanding of seasonal change a pre-/post-test design was adopted. A written questionnaire (see the appendix) featuring four items about the relevant concepts in 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 for a total of 16 questions. 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 regarding students' ideas about the causes of the 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. Table 6 summarizes the concepts addressed in the items of the questionnaire.

4.3. Results

Thirty-four students completed both the pre- and post-tests. 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 that the module activities had a substantial impact on students' conceptions. The difference between the average scores in the pre- and post-tests is statistically significant ($t = -11.956$, d$f = 33$; $p < 10^{-4}$). The distribution of correct answers for the four items[6] in the pre- and post-tests is shown in figure 4.

In the pre-test, students had particular difficulty in recognizing the role of the constant direction in space of the Earth's axis in the change of seasons (6% correct answers) and explaining the influence of the environment on the temperature at a given location (~12% correct answers). The tilt of the axis and the revolutionary motion around the Sun seem to be the two factors that students were most familiar (~20% correct answers). However, despite the fact that 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 causes for the change of seasons. Surprisingly, the idea that Earth's axis changes direction in space during orbital motion emerged in about 20% of the answers.

In the post-test, the students improved their performance for all items, especially the fourth one (~80% correct answers). Such evidence suggests that the 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 naive reasoning schemes about the causes of the seasons, centred on the distance misconception and on Earths' axis changing its direction in space. Moreover, the emphasis on thermal transfers in the fourth activity seems to have enhanced students' understanding about the basic factors that affect the climate of a region.

[6] An answer to an item was considered to be correct if the student answered correctly to all three true/false questions and to the multiple choice question.

Table 6. Description of the items of the questionnaire. Each item features three true/false questions and one multiple choice question. The total number of questions is 16. See the appendix for the complete 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 sunray inclination and length of day.
3	The Earth's revolution around the Sun and the fact that the axis tilt causes a variation of the sunray inclination on Earth's surface.
4	Because the Earth's axis always points in the same direction during its motion around the Sun the sunrays have different inclinations on Earth's surface during the year.

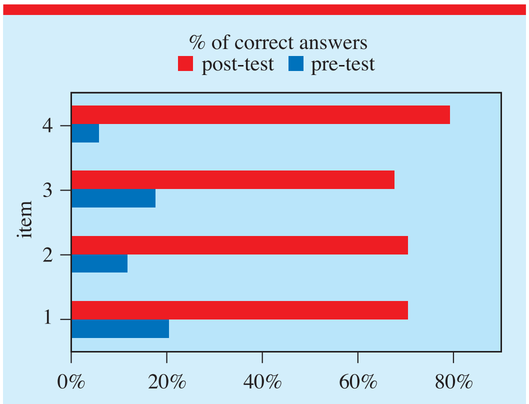

Figure 4. Distribution of students' correct answers for the four items in the pre- and post-tests questionnaire. See table 6 for item descriptions.

5. Conclusions

The difficulty students experience in trying to explain the causes of the seasons accurately has been studied widely in science education (Sneider *et al* 2011). To address this, researchers in physics education have proposed a variety of qualitative teaching approaches to correct inaccurate explanations (Kücüközer 2008, Ruangsuwan and Arayathanitkul 2009, Hughes 2010, Starakis and Halkia 2014). In this paper, we propose an innovative module where students are gradually introduced to the basic physics concepts that explain the change of seasons through simple but quantitative experiments. The module also features modelling activities that enable students to construct an interpretation mechanism for their everyday experience with the seasons. 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) 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 evidence related to the seasons. The cosine and inverse square distance laws are used to show that the effect of the tilt of the Earth's 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 from the beginning, concerning 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 and rocks) present in the environment.

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 naive 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 more experiments on the interaction between the environment and solar radiation.

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Appendix. Questionnaire used in the study[7]

1a. Indicate for each of the following sentences whether they are true (T) or false (F)

- *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 the alternation of summer and winter is:

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

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

- ***The Earth's surface absorbs energy from the Sun*** T F
- ***The temperature of a location on Earth depends on the energy transfer 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 correct explanation for Italy being hotter in the summer than it is in the winter?

- *During summer the Earth is closer to the Sun and the day is longer than in winter*
- *During summer the inclination of the Earth's axis is changed*
- ***During summer the solar rays are less inclined and the day is longer***
- *During summer the Sun produces more energy*

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

- *The axis of rotation of the Earth precesses 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 answered a question with the following statements. Who is correct?

- *The variation of the incidence of solar rays on the Earth's surface during the year is due to the revolution of the Earth around the Sun and the variation of the Earth–Sun distance*
- ***The variation of the incidence of solar rays on the Earth's 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***
- *The variation of the incidence of solar rays on the Earth's surface during the year is due to the inclination of the Earth's axis with respect to the orbit plane and to its oscillation*
- *The variation of the incidence of solar rays on the Earth's surface during the year is due to variations 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 whether 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 a highly eccentric ellipse* T F

[7] Correct answers are indicated in bold face.

- ***The periodicity of the seasons is related to the revolutionary motion of the Earth around the Sun*** T F

4b. Which of the following statements best explains the phenomenon of different seasons?

- *During revolutionary motion the Earth–Sun distance changes and hence at a given location the solar rays do not always have the same incidence on the surface*
- *During revolutionary motion the Earth's axis changes direction and hence at a given location the solar rays do not always have the same incidence on the surface*
- ***During revolutionary motion the Earth's axis remains parallel to itself and hence at a given location the solar rays do not always have the same incidence on the surface***
- *During revolutionary motion the Earth's axis is always perpendicular to the orbit plane and hence at a given location the solar rays do not always have the same incidence on the surface*

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Italo Testa is a researcher in physics education at the Department of Physics, University Federico II, Naples, Italy. Since 2008 he has taught physics education methods to prospective and in-service secondary school teachers, and to mathematics undergraduates. His main research interests are the design and evaluation of teaching–learning sequences,the enhancement of students' conceptual understanding through inquiry-based activities.

Gianni Busarello is associate astronomer at the INAF – Capodimonte Astronomical Observatory, Naples, Italy. His main research interests concern the structure and evolution of galaxies. Since 2013 he has been involved in the activities of the Piano Lauree Scientifiche Project for Physics at the University of Naples "Federico II".

Emanuella Puddu is a technologist at the INAF – Capodimonte Astronomical Observatory, Naples, Italy. Her main research interests concern extragalactic astronomy and, since 2011, she has been involved in astronomy education research, in particular the design of teaching–learning sequences for primary school pupils.

Silvio Leccia is a researcher at the INAF – Capodimonte Astronomical Observatory, Naples, Italy. He is currently involved in the GAIA project for the analysis of the light curves of Delta Scuti of pre-main sequence and the classical pulsators (RR Lyrae and Cepheid). Since 2011 he has been involved in astronomy education research, in particular the design teaching–learning sequences for secondary school students.

Paola Merluzzi is a researcher at the INAF – Capodimonte Astronomical Observatory, Naples, Italy. Her main research interests concern extragalactic astronomy, in particular the relationship between the evolution of galaxies and their environment. Since 2013 she has been involved in the activities of the Piano Lauree Scientifiche Project for Physics at the University of Naples "Federico II".

Arturo Colantonio is a teacher of mathematics and physics in secondary schools education. Since 2013 he has collaborated with the physics education group at the Department of Physics of the University of Naples "Federico II", and is involved in the activities of Piano Lauree Scientifiche Project for Physics at the University of Naples "Federico II".

Ida Maria Moretti is currently a fellow at the Scuola Normale Superiore di Pisa and collaborates with Gisella Clementini at the INAF – Astronomical Observatory, Bologna, Italy. Her main research interests concern the study of pulsating variable stars as tracers of stellar populations and distance indicators. In 2014 she was involved in the activities of Piano Lauree Scientifiche Project for Physics at the University of Naples "Federico II".

Silvia Galano has been a fellow of the physics education group at the Department of Physics of the University of Naples "Federico II" since 2013. She is currently a PhD student at the University of Camerino, Physics Division, School of Science and Technology. Her research project concerns the development and validation of learning progressions about astronomical phenomena using Rasch analysis. She is also a teacher of mathematics and science at middle school.

Alessandro Zappia has been a fellow of the physics education group at the Department of Physics of the University of Naples "Federico II" since 2013. He is currently a PhD student at the University of Camerino, Physics Division, School of Science and Technology. His research project concerns the video-based analyis of secondary school teachers' implementation of inquiry-based teaching–learning sequences. He is also a teacher of mathematics and physics at secondary school.