Publication Year	2015
Acceptance in OA	2020-04-24T17:52:00Z
Title	An Open Inquiry Research-Based Teaching-Learning Sequence About The Cause of Seasons
Authors	TESTA, ITALO, BUSARELLO, Giovanni, LECCIA, Silvio, PUDDU, Emanuella Anna, COLANTONIO, ARTURO
Handle	http://hdl.handle.net/20.500.12386/24241

Anno di pubblicazione	2015
Data inserimento in OA@INAF	2020-04-24T17:52:00Z
Titolo	An Open Inquiry Research-Based Teaching-Learning Sequence About The Cause of Seasons
Autori	TESTA, ITALO; BUSARELLO, Giovanni; LECCIA, Silvio; PUDDU, Emanuella Anna; COLANTONIO, ARTURO
Handle	http://hdl.handle.net/20.500.12386/24241

An open inquiry research-based teaching-learning sequence about the cause of seasons

Testa[1] I., Busarello[2] G., Leccia[2] S., Puddu[2] E., Colantanio[3] A.
[1] *Department of Physics, Federico II University of Naples*
[2] *INAF – Astronomic Observatory of Capodimonte*
[3] *Liceo Scientifico Medi, Cicciano, Naples*

Abstract

In this paper we describe an inquiry-based module aimed at explaining the physical mechanisms underlying the astronomical phenomenon of seasonal changes . In the module's activities, radiation flow and energy transfers are quantitatively measured by the students in simplified situations to construct the models that account for evidences related to the seasons. The module has been implemented with 45 secondary school students (17-18 years old). Analysis of students' answers to the pre- and post-test questionnaires supports the effectiveness of the proposed activities.

Keywords

Seasons, inquiry, secondary school

INTRODUCTION

Physics education research has thoroughly showed that students encounter many difficulties in understanding the causes of seasons (e.g., Atwood & Atwood, 1996; Baxter, 1989; Sharp, 1996; Starakis & Halkia, 2014). Most common incorrect explanations range from the naïve idea that when the Earth is closer to Sun it is summer, to the more sophisticated, but still incorrect, idea that the Earth's axis flips back and forth during the motion around the Sun. Still, seasons are a meaningful context to familiarise students with up-to-date topics as climate changes. Moreover, the historical evolution of the explanation of the change of seasons may illustrate to students how scientists challenge existing models to improve their understanding of a natural phenomenon (Sneider, Bar & Kavanagh, 2011). Hence, many teaching proposals aimed to improve students' understanding about this topic can be found in literature (Kücüközer, 2008). However, in most of these proposals, the physical mechanisms remain often hidden and not clarified to students.

To address this issue we developed an inquiry-based module about change of seasons. Inquiry is acknowledged as central in science learning since long time (NRC, 1996). Research shows that students may achieve a deeper understanding of science contents when they are involved in inquiry activities (Blanchard et al., 2010). Moreover, inquiry can foster young students' motivation (Mistler-Jackson & Songer, 2000) and scientific reasoning (Metz, 2000). When learners are engaged in inquiry activities, they are faced with open-ended challenges wherein new scientific knowledge would be developed. Inquiry activities are essentially student-centred and focus on improving abstraction, modelling and communication skills. Finally, inquiry approach may also facilitate the introduction of basic aspects of Nature of Science as, for instance, the relationships between experimental evidence and theoretical models or the testing of hypotheses.

In our module, scientific inquiry approach is implemented through the following steps: (i) to hypothesize which are the main factors underlying the change of seasons; (ii) to design an experiment to collect evidence to support their hypotheses; (iii) to interpret the obtained experimental results by means of simple mathematical relationships; (iv) to revise the initial hypotheses and construct a coherent explanation for the change of seasons.

RATIONALE OF THE MODULE

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. To give full account for the temperature changes during the year at a given place on Earth, the different length of the day and the influence of local climate factors (as, for instance, the presence of water, soil, and winds) have also to be considered. Actually, many research studies (see reviews by Bailey & Slater, 2004; Lelliott & Rollnick, 2010) have shown that traditional teaching activities, which often simply itemize the above factors, are not effective in addressing the intuitive idea that the changing distance between Sun and Earth is the most important factor underlying this phenomenon. How students come to this intuitive idea may be explained by everyday experience with heat sources, and by the difficulty in estimating the distance variation between Sun and Earth during the year (about 3%). Another possible explanation is that students may find difficult to relate the "energy" received by the Earth and the different conditions under which solar light hits the Earth's surface (Galili & Lavrik, 1998).

To provide a basic idea of the main physics mechanism underlying the cause of seasons, including local temperature changes, our module focuses on two key ideas: radiation flow and energy transfers. In particular, the basic idea of our module is to quantitatively show how the flow on a given surface depends on: (i) the angle between the normal to the surface and the direction of the incident radiation; and, (ii) the distance between the surface and the source. In the first case, students can model the variations of sunrays flow at a fixed time of the year over the entire Earth surface leaning towards the Sun or, equivalently, at a fixed place on the Earth's surface as our planet completes its revolution around the Sun. In the second case, they can model the variations of sunrays flow when the Earth has the maximum and minimum distance from the Sun. The main didactical aim is to provide students with evidence that greatly contradicts naïve reasoning schemas based on the distance misconception. Then, having shown the relevance of the tilted axis with respect to the small eccentricity of the Earth's orbit on the change of seasons, it is possible to address why places of the Earth at the same latitude experience very different average temperatures over the year. To this aim, to provide the students with simple evidence about the relevance of the factors that affect a given region climate (for example, presence of water and soil), it is possible to show how heat transfers depend on the substances involved in a thermal interaction.

ACTIVITIES OF THE MODULE

The module is divided into four activities, which we describe in the following paragraphs reporting also typical students' responses. All activities are supported by worksheets.

Introductory activity (4 hours)

In this activity the students, in small groups, are asked to define what is a season and how do they know that we are in a certain season. The question "*what are the main factors that influence change of seasons?*" is raised in order to elicit naïve conceptions about change of seasons (e.g., the distance misconception). Examples of students' possible responses are:

"*The factors that influence the change of seasons are the variations of temperature due to the changing distance between the Earth and the Sun".*

"The seasons depend on the motion of revolution of the Earth and on the inclination of the Earth: during the perihelion the inclination of the Earth is such that the sunrays hit its surface so that it is summer in austral hemisphere and winter in the boreal one; while during the aphelion, it is the contrary".

"The change of seasons is due to the motion of revolution of Earth which modifies the inclination of the Earth's axis. The different inclinations cause the different inclinations of the sunrays on Earth's surface".

Then, the students are asked what would be the effect on seasons changes of the absence of the identified factors. The aim is to investigate the coherence of the students' initial explanations about seasonal changes. Possible students' responses may be:

"If the Earth would not rotate around the Sun, there would be always the same season or the same temperature".

"If the Earth's axis would not be inclined, we would have fixed temperatures".

"If the Earth's orbit would not be elliptical, we would have no seasons".

"If the Earth's axis would change direction we would experience more seasons".

After a class discussion about students' responses, it is 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 can relate the identified factors with physical quantities that can be measured. The teacher may focus solely on two factors, as the inclination of the Earth's axis and the changing distance between Earth and Sun. A possible experiment proposed by the students is the following:

"I would use a light in the focus of on ellipses, a plastic globe covered with a photosensitive material and I would measure the light intensity when changing the distance between the globe and the light and the inclination of the globe's axis with respect to the Sun's axis".

Experimental activity about the radiation flow (4-6 hours)

In this core activity of the module, the students investigate the relationship between the different quantity of solar radiation received by a specific location on Earth during the year and the two factors identified in the previous activity, the tilt of the axis and the distance from the Sun. The students are told that radiation flow is a power per surface unit and hence it can be measured through a device that transforms the intensity of received light into a potential difference. A photovoltaic panel[1] and an incandescent light bulb (a laboratory "Sun") are used. Before performing the experiments, the students predict what would be the trend of the measured power when the incidence angle and the distance are varied. Examples of predictions are shown in Fig. 1a and 1b.

(a) (b)

Figure 1. Students' predictions about the relationships between light intensity and the incident angle on the panel surface and the distance beween the source and the panel (a) correct (b) incorrect.

Then, the students measure the output voltage of the panel as its inclination with respect to a given reference system and its distance from the source change with the setting of Fig. 2a and 2b.

(a) (b)

Figure 2. 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. 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.

---

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

After comparing the predictions and the obtained measurements, the teacher may guide students to represent the data as in Fig 3 and 4. Particular emphasis is put on what would be the mathematical function that best fit the collected data. Depending on the pupils' school level, the teacher may deepen the mathematical behaviour of the best fit functions.

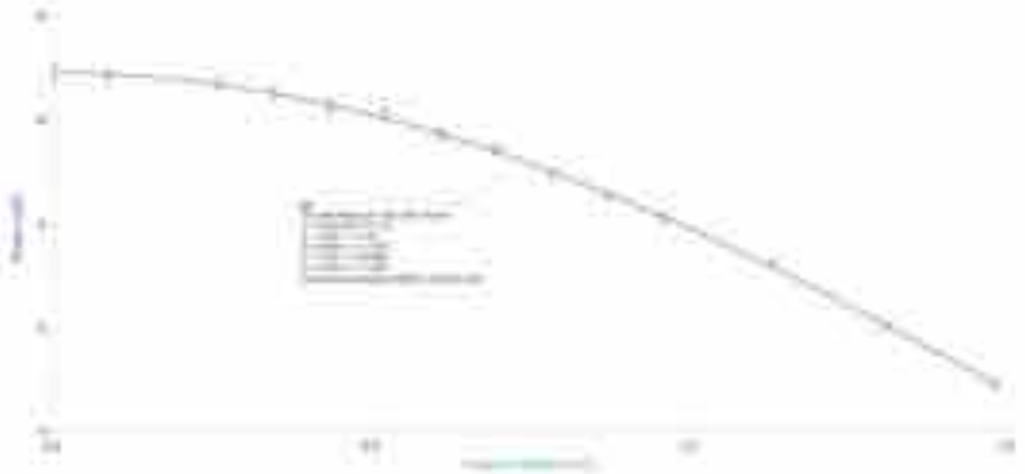

Figure 3. Output power of the panel lighted by a 100W incandescent lamp as a function of the inclination between the normal to the panel and the direction of the radiation. The fit gives: $P(\theta) = A\sin(B\theta + C) + D$, with $A = (7.3 \pm 1.7)\,\mu W; B = (0.93 \pm 0.14)\,rad^{-1}; C = (1.58 \pm 0.03)\,rad; D = (-0.4 \pm 1.7)\,\mu W$.

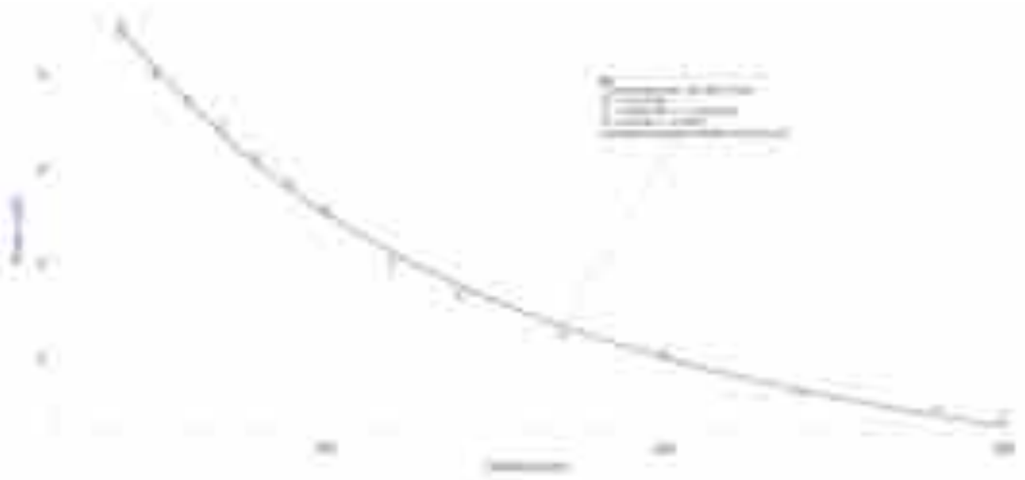

Figure 4. Output power of the panel lighted by a 100W incandescent lamp as a function of the distance between the centre of the panel and radiation source. The fit gives $P(D) = \frac{A}{D^{2+B}}$ with $A = (7.1 \pm 1.2)\,\mu W m^2; B = (0.02 \pm 0.03)$.

Finally, simplified laws for the power received by the panel are presented to students (equations (1) and (2)). 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, and 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.

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

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

Modelling activity (4 hours)

Using equations (1) and (2) the students first evaluate the incident radiation flow at four times of the year (spring and autumn equinoxes, summer and winter solstices) at five specific places on Earth (Arctic and Antarctic circle; Cancer and Capricorn tropic; Equator) using the information of printed images constructed with Cabrì Géomètre (Fig. 5). Contrarily to usual teaching about the topic, during the activity, a great portion of time is devoted to link 2-d textbook representations to the real Earth and Sun system through the Cabrì Géomètre representations. The aim is to guide the students to understand that, for a given place, the different angles reported in the textbook images result from the fact that the Earth's axis always points in the same direction and from changes in the position of the Earth along its orbit.

Figure 5. Cabrì representation showing the angles formed by the sunrays at summers' solstice w.r.t. the tangent plane in specific Earth regions.

Then, drawing from the experimental activities results, students calculate the difference:

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

for the five given locations of the Earth at the four times of the year. The angles θ_w and θ_s correspond to the winter and summer solstices for tropics and Equator, and to the summer/winter solstices and autumn/spring equinoxes for Arctic and Antarctic Circle, respectively. Finally, students calculate the difference:

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

and compare the result with that obtained for the five locations of the Earth from equation (3). In this way, the teacher can easily show that the difference in the radiation flow 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). In such a way, the distance misconception can be quantitatively addressed.

At the end of the session, the teacher recalls what the students had predicted in the first activity about the absence of one of the identified factors (tilt of the axis, Earth-Sun distance) and compare their predictions with those of the discussed models. Hence, they are guided to understand that at a certain location, *without* any axis inclination, there would be only one season and the duration of night/day cycle would be the same all over the Earth's surface and along the whole year. Similarly, the teacher may underline also that, in the case of a perfectly circular orbit, the only effect would be an equal duration of the seasons due to the constant angular velocity of the planet (actually, the small eccentricity results in a difference of few days in the relative duration of the seasons).

Specific heat activity (2-4 hours)

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 climate map is given to the students. 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. Students can then understand that, in principle, both the duration of exposition to the incident radiation and energy transfers with the environment affect the temperature of a given location on Earth. However, the activity is aimed at showing that energy transfers mainly depend on the environment. A simple model of thermal interaction is proposed, focusing in particular on the role of specific heat of involved substances. Students are asked to design another experiment in which they can evaluate the effect of such property. A typical experiment that students can easily perform involves the thermal interaction between water and a substance with unknown specific heat. For this activity we chose sea sand 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 $c_{water}=1\ cal\ g^{-1}{}^{\circ}C^{-1}$), 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 $T_{isand}<T_{iwater}$. Hence, using the equilibrium relationship: $\frac{c_{sand}}{c_{water}}=\frac{m_{water}\left(T_{iwater}-T_e\right)}{m_{sand}\left(T_e-T_{isand}\right)}$, they can estimate the ratio $\frac{c_{sand}}{c_{water}}$ which should be around 0.3 - 0.4[2]. In such a way, students may justify how the presence of water contributes to the radiation transfer to the environment.

---

[2] A table of common substances specific heat can found at http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html. A typical average value of the specific heat of sand relative to water is 0.37 ± 0.06

EVALUATION OF THE MODULE

The module was implemented with 45 secondary school students (17-18 years old) in South Italy, for a duration of 16 hours. The students had already studied 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 whether the module's activities could improve students' conceptual understanding of seasonal changes from the physics viewpoint.

A written questionnaire featuring 16 questions about the relevant concepts of the module was submitted to the sample before and after the activities. The questions were organized into four items, each related to a factor underlying the cause of seasons, namely: the motion of the Earth around the Sun (*item 1, Q1-Q4)*; the influence of the environment on the temperature at a given location (*item 2, Q5-Q8)*; the inclination of the Earth's axis (*item 3, Q9-12)*; Earth's axis constant direction in space (*item 4, Q13-Q16)*. Each item had a two-tier structure: the first tier featured three true/false statements, the second tier one multiple choice question. The true/false statements concerned basic facts that the student should know to answer the multiple choice question. The multiple choice question 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 the multiple choice question, 1 point was given, so that the total possible score was 10.

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 (as measured by a t-test: $t = -11.956, df = 33; p < 10^{-4}$). The distribution of students' correct answers to the four items[3] in the pre- and post-test is shown in Figure 6.

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 used the most 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

---

[3] An answer to an item has been considered correct if the score was maximum for the three true/false questions (1.5 points) and the multiple choice question (1 point)

inclination of radiation flow on Earth's surface helped the students abandon naïve reasoning. Moreover, the emphasis on the thermal transfers in the fourth activity seems to have increased students' understanding of the basic factors that affect the climate of a region.

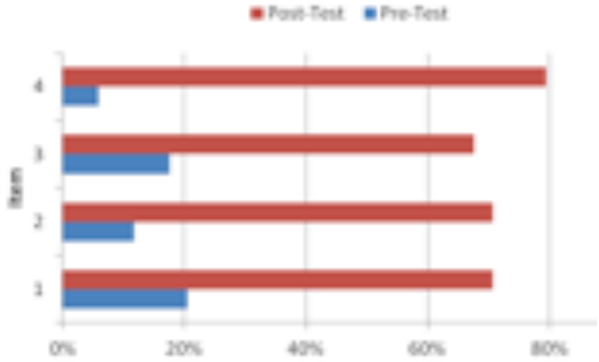

Figure 6. Distribution of students' correct answers for the four items in the pre- and post-test questionnaire. Each item featured 3 true/false questions and 1 multiple choice question.

CONCLUSIONS

In this paper, we have presented an inquiry-based module where students are gradually introduced to the basic physics concepts underlying the change of seasons. The module features both experimental and modelling activities to let students construct an interpretation mechanism for their every day experience with the seasons phenomenon. In particular, 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 evidences related to the seasons. The radiation flow is introduced to justify the existence of different seasons, since it changes over the Earth's surface through the year. The cosine and inverse square laws are used to show that the effect on the radiation flow due to the tilt of the axis is greater than that of the change of the Earth – Sun distance. Students are engaged in discussions 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, specific heat of the sand with respect to water is used to interpret basic aspects of the energy transfers between the radiation and the substances (soil, water, rocks) that are present in the Earth's environment . 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 axis may change direction in space seem to have been successfully addressed. We plan to improve the module by designing an activity with Cabrì Géomètre about the visualization of the incident radiation flow during the motion of the Earth and by completing the teachers' notes.

References

Atwood, R. K. and Atwood, V. A. (1996) Preservice elementary teachers' conceptions of the causes of seasons *J. Res. Sci. Teach.* **33,** 553–563

Bailey, J. M. and Slater, T. F. (2004) A review of astronomy education research *Astron. Educ. Rev.* **2,** 20–45

Baxter, J. (1989) Children's understanding of familiar astronomical events *Int. J. Sci. Educ.* **11**, 502–13

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A. and Granger, E. M. (2010), Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, **94**, 577–616.

Galili, I. and Lavrik, V. (1998) Flux concept in learning about light. A critique of the present situation *Sci. Educ,.* **82,** 591–614

Hake, R. R. (1998) Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses *Am. J. of Phys.* **66,** 64-74

Küçüközer, H. (2008) The effects of 3D computer modelling on conceptual change about seasons and phases of the Moon, *Phys. Ed.* **43,** 632-636

Lelliott, A. and Rollnick, M. (2010) Big ideas: A review of Astronomy education research 1974-2008. *Int. J. Sci. Educ.* **32,** 1771-1799

Metz, K.E. (2000) Young children's inquiry in biology: building the knowledge-bases to empower independent inquiry. In J. Minstrell & E. van Zee (eds), Inquiring into Inquiry Learning and Teaching in Science. American Association for the Advancement of Science: Washington DC, 371-404.

Mistler-Jackson, M.,&Songer, N. B. (2000). Student motivation and Internet technology: Are students empowered to learn science? *Journal of Research in Science Teaching*, **37**, 459 – 479.

NCR [National Research Council] (1996). National Science Education Standards: Observe, interact, change, learn. Washington, DC: National Academy Press.

Sharp, J. G. (1996) Children's Astronomical beliefs: a preliminary study of year 6 children in southwest England *Int. J. Sci. Educ.* **18,** 685–712

Sneider, C., Bar, V. and Kavanagh, C. (2011) Learning about Seasons: A Guide for Teachers and Curriculum Developers. *Astronomy Educ. Rev,* **10** *010103-1–010103-22*

Starakis, I. & Halkia, K. (2014) Addressing k-5 students' and pre-service elementary teachers' conceptions of seasonal change *Phys. Ed.* **49,** 231-39

Trumper, R. (2000) University Students' Conceptions of Basic Astronomy Concepts *Phys. Educ.* **35,** 9-15.

Affiliation and address information

Italo Testa
Department of Physics
University "Federico II" Napoli
Complesso M.S. Angelo,
Via Cintia 80126, Napoli, NA,
Italy
e-mail: italo@na.infn.it