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Integrating Practice-Based Activities and Visual Representations to Foster Students' Understanding of Basic Astronomy Phenomena: An Example about Seasonal Changes

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Abstract

This study investigates how different combinations of practice-based activities and visual representations affect students' learning about seasonal changes. We adopted a pre-post 3 × 2 experimental design in which we first randomly assigned 12 intact 9th-grade classes ($N = 337$ students) to either a "practice-based activity" or a "no practice-based activity" and then to one of the following conditions: "specially designed images"; "textbook images"; "no images". We used a draw-and-explain task and a mixed multiple-choice true/false questionnaire, the Seasons Concepts Inventory (SCI), to assess students' conceptual understanding of seasons before and after participating to one of the teaching conditions. Data were analyzed using a 2-way between subjects factorial analysis of variance (ANOVA). The results indicate a significant interaction effect between the experimental conditions. Students in the "practice-based activity" condition outperformed students in the "no practice-based activity" condition, regardless of the type of image used. However, the students in the "specially designed images" condition performed significantly better than those in the "textbook images" and "no images" conditions in both the draw-and-explain task and the SCI instrument, regardless of the practice-based activity condition. Furthermore, the students in the "no practice-based activity" condition who were taught with the specially designed images did not perform significantly different from the students in the "practice-based activity" condition who were taught with the same types of images. Our study has implications for astronomy education practice in that it shows advantages and limitations of combining two approaches that are usually implemented separately. This study has also broader educational implications in that it demonstrates that when combining two different teaching approaches, the effectiveness of each approach may depend on the specific combination adopted.

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Introduction

The presence of astronomical topics in all school curricula has gradually increased in recent years for several reasons. First, research studies have shown that astronomy has a unique ability to capture students' imagination and spark their curiosity about the universe, leading to greater interest in science, technology, engineering and mathematics (STEM) disciplines and careers, regardless of students' age or cultural background (Salimpour et al., 2021). Second, understanding basic astronomical concepts can help students develop an informed view of the Nature of Science (NOS) by providing an example that there is no single scientific method (Percy, 2005). In addition, learning about astronomical topics can improve students' critical thinking skills and their ability to understand and interpret scientific information (Taasoobshirazi et al., 2006), helping them to see the connections between different areas of science and to understand the broader applications of scientific knowledge (Ward et al., 2007). Finally, teaching astronomy helps students to appreciate the historical and cultural contexts of scientific discoveries and the impact of astronomy on our understanding of the world (Salimpour & Fitzgerald, 2024).

The focus in school astronomy curricula, however, is generally limited to topics related to celestial motion and the solar system, and specifically on well-known and familiar astronomical phenomena such as lunar phases, solar and lunar eclipses, and seasonal changes (Salimpour et al., 2024a, b). Among these phenomena, seasonal change allows students to meaningfully relate their everyday Earth-based observations of the apparent daily motion of the Sun to celestial motion (Plummer & Krajcik, 2010). Understanding how seasons change involves visualising the Earth's position relative to the Sun, which contributes to spatial thinking (Cole et al., 2018; Plummer et al., 2016, 2022) and fosters three-dimensional extrapolation skills (Eriksson & Steffen, 2019). Recent studies indicate that learning about the seasons can help students develop critical thinking (Fleer, 2023), as well as recognize patterns, observe changes, and make connections between celestial events and their effects on Earth (Eriksson, 2019; Eriksson et al., 2014). Other studies suggest that students engaged in learning activities about the seasons can develop skills related to obtaining, evaluating, and communicating information (Chen et al., 2007; Türk & Kalkan, 2015) and evaluating scientific models (Lee & Feldman, 2015). Finally, similar to other astronomical topics, seasonal changes can be a fruitful cross-cutting context to address content that is usually taught separately in different school curricula, such as mathematics, earth science, physics and biology (Rodrigues et al., 2025 ; Salimpour et al., 2021; Sneider et al., 2011). In summary, teaching students about the seasons can help to connect students to broader scientific concepts and stimulate a lasting interest in and deeper awareness of the relevance of astronomy.

However, for more than thirty years, research studies in astronomy education have thoroughly shown that students' alternative conceptions about seasonal changes are widespread and resistant to traditional teaching (Atwood & Atwood, 1996; Salimpour et al., 2024a, 2024b; Sharp, 1996; Slater, et al., 2018; Trumper, 2006).

Typically, most misconceptions about change of seasons are grounded on a distance-based reasoning. For instance, students think that, as the Earth rotates around the Sun, it moves closer to the Sun in summer and further away from it in winter (Baxter, 1989). Students may also think that the tilt of the Earth's axis with respect to the orbit's plane brings some parts of the Earth closer to the Sun than others, namely, in the regions that lean towards the Sun it is summer, while in those that are furthest from the Sun and closest to the Moon it is winter (Starakis & Halkia, 2014). Literature has also shown that teachers may be not aware of or hold the same alternative conceptions of their students, thus increasing the likelihood that students will maintain their incorrect ideas after formal instruction (Cox et al., 2016). Based on these results, different types of teaching approaches have been proposed to improve students' conceptions about the seasons (e.g., Bakas & Mikropoulos, 2003; Plummer & Maynard, 2014; Testa et al., 2015; Yu et al., 2015). In this study, we aim to investigate the extent to which different combinations of two specific teaching approaches – one based on practice-based activities, the other on visual representations – may be helpful in teaching seasonal changes. In the following, we review previous work about the use of the two approaches to teach change of seasons.

Review of Literature

Use of Practice-Based Activities to Teach Seasonal Changes

Practice-based approaches are defined as learning environments that promote meaningful understanding of concepts through the active investigation of phenomena (Abrahams & Millar, 2008) and include activities such as measuring, classifying, experimenting, analysing data and drawing reasoned conclusions (Arnold et al., 2023). Practice-based approaches have been widely adopted in astronomy education to let students use real astronomical data (Fitzgerald et al., 2015) and to promote achievement (Taasoobshirazi et al., 2006), engagement (Chen et al., 2016) and understanding of the process of knowledge generation by scientists (Cirkony, 2023). In addition, practice-based approaches are often implemented in professional development courses on teaching astronomy at both primary and secondary levels (Fitzgerald, 2022; Fitzgerald et al., 2019; Plummer & Tanis Ozcelik, 2015). When used to teach about seasonal change, practice-based approaches often involve direct manipulation of concrete models of the Earth or the Sun to help students develop a qualitative explanation of seasonal change based on the Earth's orbit and axial tilt (Covitt et al., 2015; Frede, 2008; Plummer & Maynard, 2014). For example, in the activities described in Plummer and Maynard (2014), students moved a polystyrene ball representing the Earth around a light bulb representing the Sun and measured the changes in the intensity of the incident light as the ball moved away from and towards or around the bulb. Practice-based approaches can also help students to develop, evaluate and revise competing models that account for seasonal changes. For instance, Covitt et al. (2015) proposed a 9-step activity sequence to explore the shape of the Earth's orbit, the impact of sunrays on the Earth, the relationship between the Sun's daily altitude and the observer's latitude and time of year and the relationship between temperature and inclination of Sunrays. In the Türk and Kalkan (2018) study, three concrete models of the Sun-Earth system were constructed for use with middle school students: the experimental group used a model with a tilted Earth axis, the control group either used a model with an Earth without axial tilt or a simple Sun – Earth – Moon model. Students were instructed to use the models and observe how the illumination of the Earth changed while it orbited around a light source that simulated the Sun. The analysis of the students' explanations and drawings revealed that the experimental group outperformed the control group in the post-test. Finally, Chastenay (2023) developed an activity sequence to help students understand the apparent motion of the Sun in each hemisphere of the Earth and the effects of sunrays different inclination. This is achieved through observation data of the Sun's path in two places at the same longitude and latitude, but in different hemispheres, while using also as concrete models a polystyrene ball and a lamp to represent the Earth and the Sun, respectively. At the end of the activities, students can understand that seasonal changes are related to the length of the day and the height of the sun in the sky. The activity sequence was implemented only with a small sample ($N=37$) of prospective teachers and assessment was limited to the analysis of a pre- and post-test. Overall, it is apparent from the above review that although authors often place a strong emphasis on the proposed activities as a way to address students' misconceptions about seasonal change, in most cases it is not clear how interaction with the concrete models helps students to understand the more general physical mechanism underlying seasonal changes.

Use of Visual Representations to Teach Seasonal Changes

Research has systematically shown that typical textbook representations of astronomical phenomena are difficult to interpret (Lelliott & Rollnick, 2010; Ojala, 1992) and may even lead students to incorrect reasoning strategies (Testa et al., 2014). According to semiotic theory, such difficulties are related to the interaction between different types of visual representational structures (Lemke, 1998a, 1998b). In other words, the difficulties in interpreting the message encoded in a visual representation are related to the meaning that the user gives to the graphical signs, such as symbols, labels, lines, as well as their relative spatial position within the representation. For this reason, the mere presence of photographs, drawings and diagrams in textbooks does not guarantee greater effectiveness of visualizations in communicating scientific concepts (Guo et al., 2020; Lee & Feldman, 2015; Roth et al., 2005). Furthermore, in the case of astronomical topics, the interpretation of visual representations is complicated by the fact that they often depict phenomena, such as seasonal changes, that always evolve over time in a 3-dimensional space (Galano et al., 2018). For example, in typical textbook representations of seasonal changes, the Earth's orbit is shown with an exaggerated eccentricity, and the four positions of the Earth, which mark Equinoxes and Solstices, are shown together in the same diagram (Testa et al., 2014).

In view of these difficulties, teaching approaches based on innovative and visual representations have been developed, starting from research results, to better explain the dynamics of the Sun-Moon-Earth system and to help students develop perspective-taking skills useful for explaining seasonal changes. Examples of innovative visual representations include specially designed static 2D images (Mason et al., 2017), computer-based animations (Küçüközer, 2008), and 3D simulations (Sun et al., 2010; Türk & Kalkan, 2015). Among the 2D static images, refutation images have been suggested as an effective support to help students overcome typical misconceptions in science (Mason et al., 2017). A refutation image aims to address a given misconception by first explicitly acknowledging the misconception and then presenting the correct conception (Danielson et al., 2016). To address the distance misconception, Mason and colleagues used refutation graphics that included a visual representation with two-sided images of the Earth orbiting the Sun. The images included Earth tilted axis and explicit indications of the dates of solstices and equinoxes. A refutation mechanism was implemented graphically by labelling the image with a NO when the Sun is closer to the Earth at the summer solstice and labelling the image with a YES when the Sun is closer to the Earth at the winter solstice. In both studies reported in the paper, the authors found mixed evidence regarding the effectiveness of the refutation graphic in overcoming the distance misconception. Using a semiotic perspective, we argued that such mixed evidence was probably due to the refutation image still depicting a highly eccentric Earth's orbit (Galano et al., 2018). In other words, despite the presence of the refutation graphics, the eccentric Earth's orbit interfered with the identification of the main mechanism underlying seasonal changes (Yu et al., 2010). Küçüközer and colleagues (2009) developed a series of 3D animations illustrating various astronomical phenomena, such as day and night, seasons, phases of the Moon, and stars. The activities employed a predict-observe-explain approach, which allowed students to compare their initial explanations with their observations made through the computer animations. However, the authors do not explain how the designed animations aided the students in enhancing their understanding of seasonal changes. In relation to planetariums, Yu et al. (2015) compared the understanding of seasons among three groups of students who were exposed to different teaching conditions: (i) lecture + immersive virtual representation in a planetarium; (ii) lecture + visualization projected onto a flat screen in the classroom; (iii) lecture + no visualization. All three groups used the same textbook. The study provides evidence for the effectiveness of using a 3D representation to teach seasonal changes. In particular, the authors discovered that the group exposed to immersive virtual representations of seasonal changes had a greater learning gain in both the post-test and the delayed test, while the other two groups showed smaller gains. However, the research design does not clarify whether the reported gains were solely due to the multi-modal immersive experience, the dynamical nature of the virtual representations, or their superior quality in fully representing a three-dimensional representation of the Earth-Sun system. Recently, De Paor et al. (2017) developed an interactive computer model using the Google Earth app to demonstrate the role of the Earth's fixed axis inclination with respect to the ecliptic plane, the altitude of the Sun, and the length of the day on season's change. The students are also guided to distinguish between the daily rotation of the Earth around its axis and its orbit around the Sun and to recognize that events such as solstices and equinoxes correspond to different locations of the Earth around its orbit. Although the authors extensively discuss how interacting with the computer model can help students understand the role of factors affecting seasonal changes, they do not provide an explicit reference to an activity sequence that can scaffold students' understanding of the physical mechanism underlying seasonal changes.

Aims of the Study

The above literature review shows that the teaching of seasonal change often follows a single approach, either practice-based with concrete models or centered around visual representations of the Earth-Sun system. However, if, in the controlled environment of a practice-based activity, students only manipulate the concrete analogues of the relevant factors underlying seasonal change (such as the Earth's tilt, its rotation around the Sun, and the Earth-Sun distance), they are rarely guided to link how these factors can be framed in terms of a space observer's view of the Earth-Sun system. Therefore, these activities alone are unlikely to sufficiently help students construct a scientific explanation of the dynamics of the Sun-Moon-Earth system and develop the appropriate perspective-taking skills needed to understand the phenomenon of seasonal change (Plummer et al., 2016). Similarly, when students are only exposed to visual representations, such as those found in typical textbooks, the graphical signs used, such as symbols, labels, lines and colours, are not explicitly linked to the physical properties of the Earth-Sun system. Therefore, this approach is unlikely to allow students to build a working model of the phenomenon of seasonal change (Vosniadou, 2010). Although previous studies have provided evidence that the use of different types of teaching approaches can lead to improvements in students' understanding of astronomical phenomena (Chubko et al., 2019; Rule & Webb, 2015), the literature has not yet adequately explored whether the interaction between the two approaches reviewed – practice-based activities and visual representations – could improve or hinder students' understanding, which is crucial for advancing research in astronomy education. This gap is significant from a classroom perspective, as understanding how these approaches complement or compete with each other could provide valuable insights for designing astronomy curricula and enhancing teaching practices. On this basis, in this study we aimed to investigate to what extent students exposed to both types of approaches show a better understanding of seasonal change compared to those exposed to neither or only one approach. Therefore, the study was guided by the following research question:

> RQ: How do teaching conditions that use different combinations of practice-based activities and types of images influence students' conceptions of seasonal changes?

Specifically, the present study aims to investigate how different types of static visual representations contribute to the learning of seasonal changes with and without practice-based activities. The reason for focusing on static visual representations is that, while to understand why seasonal changes occur can be difficult because it is an inherently dynamic phenomenon that requires an understanding of how the geometry of the Earth's orientation relative to the Sun changes over time, the practice of teaching astronomy is generally still based on textbook, with an emphasis on static visual representations. Therefore, among the different types of visual representations, it is still worth investigating those that are most commonly used in teaching practice, namely the static ones.

Methods

Sample

We recruited the participants for this study through an open call for research collaboration for high schools (9th – 13th grade) published on the authors' university website and sent by e-mail to the Regional School Office to the school district. The reason for limiting the call to high schools was that the topic of seasonal changes is included, as for other introductory astronomy topics, in the national curriculum indications for this type of school at 9th grade. Three high schools, which had already participated in research-based curriculum innovations in previous years, responded on a voluntary basis and sent to us the formal authorization of the headmaster to carry out the study with their students. We then sent to the three schools an informed consent document in agreement with the Italian Privacy and Data Protection Act (196/2003) and with the European General Data Protection Regulation (2016/679), to be signed by the students' parents in order to obtain the permission to use the collected responses for research purposes. The first author organized a 4-h workshop at the university with the participating schools' teachers to briefly explain the purpose of the study and to show the practice-based activity that the students would have carried out during the intervention. The booklets that the students would have used were also presented and discussed. All the participating teachers taught the Natural Sciences subject since seasonal changes are included in this subject's syllabus at 9th grade. The teachers assigned an identification number to the students in order to submit a pre-test two weeks before the beginning of the activities and a post-test about two weeks after the end of the intervention. We involved only the students who had not yet received the curricular instruction about seasonal changes and whose parents gave the authorization to use their responses for research, resulting in a sample size of $N = 337$ 9th grade students (average age = 14 years old) from 12 intact classrooms.

Experimental Design

To answer our research question, we adopted a *2×3* between-subjects factorial experimental design. A power analysis carried out with G*Power (Faul et al., 2007) revealed that to detect a small to moderate effect size (0.2) for the main effects and interactions between two variables at $\alpha = 0.05$ significance level with a power of 0.90, a sample size of 320 subjects would be needed. Therefore, given the collected parents' authorizations, we deemed as feasible the chosen research design. We then randomly assigned the recruited classes to a *"practice-based activity"* (6 classes, total number of students in this condition, $N = 170$) and a *"no practice-based activity"* (6 classes, total number of students in this condition, $N = 167$) condition using the Microsoft Excel functions rand (), index () and rank.eq ().

In the "practice-based activity" condition, the module called "Cause of seasons" was implemented (Testa et al., 2015; see Supplemental Material). The aim of the module is to help students understand the physical mechanisms behind seasonal changes through experiments and quantitative measurements. Specifically, students first discuss the possible factors underlying seasonal changes and then design an experiment to demonstrate the relevance of the identified factors. During the experimental phase, the students measure the power output of a photovoltaic panel illuminated by a light bulb and vary the distance between the source and the panel and the inclination of the panel. Students are then guided to derive from the experimental data two competing mathematical models – a distance model and an inclination model – to estimate the solar radiation flux at different locations on Earth at a given time of year and at a given location over the year. Based on the evidence collected and the actual distances and quantities (e.g., Sun-Earth distance, inclination of the sun's rays on the Earth's surface), students are asked to argue which of the two competing models can better explain the seasonal changes.

In the "no practice-based activity" condition, the first activity was the same as that of the "practice-based activity" condition and was aimed at discussing the possible factors underlying the change of seasons. Then, after a class discussion aimed at comparing the relevance of the factors identified, the students were taught the same physical laws introduced in the "practice-based activity". Differently from the "practice-based activity", in the "no practice-based activity" the mathematical models were not derived by the students from actual measurements but explained by the teacher. The last activity was the same as that of the "practice-based activity" condition. Peer interaction was also encouraged to facilitate the comparison between the two groups.

Then, each of the 12 classes was randomly assigned again using Microsoft Excel functions to one of the three further conditions: *"specially designed images"* (4 classes, $N = 55$ in the "practice-based activity" condition and $N = 54$ in the "no practice-based activity" condition, respectively, total number of students $= 109$); *"textbook images"* (4 classes, $N = 56$ and $N = 60$, respectively, total $= 106$); *"no images"* (4 classes, $N = 59$ and $N = 53$, respectively, total $= 102$). The "specially designed images" condition was based on the teaching module called "Images of Seasons" (Galano et al., 2018; see Supplemental material). In order to better control for interaction effects, students in all conditions were first given a teaching booklet with different types of text and images, and then, after reading the booklet, were instructed to relate the features of the images studied to the mechanism underlying seasonal changes. In particular, in the "specially designed images" condition, students were given images designed by us to address several specific misconceptions that students often have about astronomical phenomena. For example, to address the distance misconception, we designed an image that used a circular orbit to avoid emphasizing distance. Similarly, to address the tilt misconception, the idea that the Earth's axis tilts back and forth, we showed the tilt of the Earth's axis from different perspectives in the images, emphasizing its constant direction in space.

The "textbook images" condition followed the same reading session – guided discussion sequence as that of the "specially designed images" condition, except that the students used an adapted text and the images from their textbook (see Supplemental material). For the "no images" condition, the students used a different booklet in which we reproduced textbook parts excluding the images (see Supplemental material).

Overall, for each condition, the intervention lasted 6 curricular hours. All the activities were jointly carried out by the first author and by the classroom teacher during regular curriculum hours. The reason for letting the first author join the teacher was to ensure similarities across the conditions. The sample distribution in the six conditions is summarized in Table 1.

Instrument

We used as research instruments a draw-and-explain task and the Seasons Concept Inventory (SCI), which features two multiple-choice and six true/false items (see Appendix for the complete instruments). In the draw-and-explain task, the students were asked to represent the mechanism causing the change of seasons through a drawing and to explain with few written sentences why seasonal changes occur. The prompt was: *Please explain with a drawing and in words why the phenomenon of the changing seasons occurs in Italy.* Draw-and-explain tasks have been widely used to examine students' conceptions about astronomical topics (e.g., Galano et al., 2018; Neofotistos et al., 2024; Oh, 2014; Testa et al., 2023). The SCI instrument used in this study was adapted from previous instruments developed in astronomy education research (Danaia & McKinnon, 2007; Trumper, 2001a).

The draw-and-explain task and the SCI were submitted as post-test at the end of the activities. Participants completed the SCI after completing the draw-and-explain task. The SCI was given also as pre-test to inform a baseline comparison between the six groups.

Table 1 Distribution of the students (n) in the six teaching conditions

Image condition	Practice-based activity condition	
	"Cause of seasons"	No practice-based activity
"Specially designed images"	55	54
"Textbook images"	56	60
"No images"	59	53
Total number of students	170	167

Data analysis

Drawings Analysis

Students' drawings were analyzed as follows. First, we coded the drawings according to a list of graphical elements (e.g. circles, lines, labels, arrows, numbers, words etc..). The list was generated in a previous study, where, using an innovative method based on categorical factorial analysis, we grouped the graphical elements in distinct latent categories of drawings representing different models of the represented phenomenon (Testa et al., 2023). Then, we categorized each drawing in the present study using the coding scheme and the models emerged from that previous study. The described procedure lead to the identification of three categories: 1) drawings that represent the personal and sensorial experience of the student about the seasonal changes, with no mechanism represented ("*naïve*"); 2) drawings featuring some visual reference to the changing distance between Sun and Earth to explain seasonal changes is included ("*distance-based*"); 3) drawings relating the change of seasons to the changing inclination of sun's rays during the year, with an indication also to the Earth's orbital motion and axis' tilt ("*inclination-based*"). The drawings were analyzed by the two authors through the constant comparison (Strauss & Corbin, 1998) between the original categories and the students' produced representations collected for this study. Inter-rater reliability was evaluated through Cohen's κ obtaining a satisfactory value, $\kappa = 0.85$. Examples of student drawings for each of the emerging categories are reported in Fig. 1a-c. Further examples of drawings and corresponding categories are reported in the Supplemental Material.

Written Explanations Analysis

As for the drawings, we analyzed students' explanations using the rubric developed and refined in our previous studies (Galano et al., 2018; Testa et al., 2023). The rubric features 5 categories: i) *unclear* (e.g., non-relevant or vague explanations); ii) *distance-based* (e.g., explanations in which seasons are due to the changing Sun-Earth distance); iii) *mixed incorrect* (e.g., explanations in which seasons are due to the changing inclination of the Earth's axis); iv) *partial* (e.g., explanations that refer only to observable consequences of the seasonal changes, or to only one of the factors that cause seasonal changes); v) *correct* (e.g., explanations that refer to factors and to a sort of causal mechanism underlying seasonal changes). After a refinement that collapsed the unclear, distance-based and mixed incorrect categories we arrived at the following macro-categorization: *incorrect; partial; correct*. The analysis was carried out by the two authors through the constant comparison between the categories and the students' explanations with a resulting Cohen's $\kappa = 0.85$. Examples of students' explanations and more details on the categorization adopted are reported in the Supplemental material.

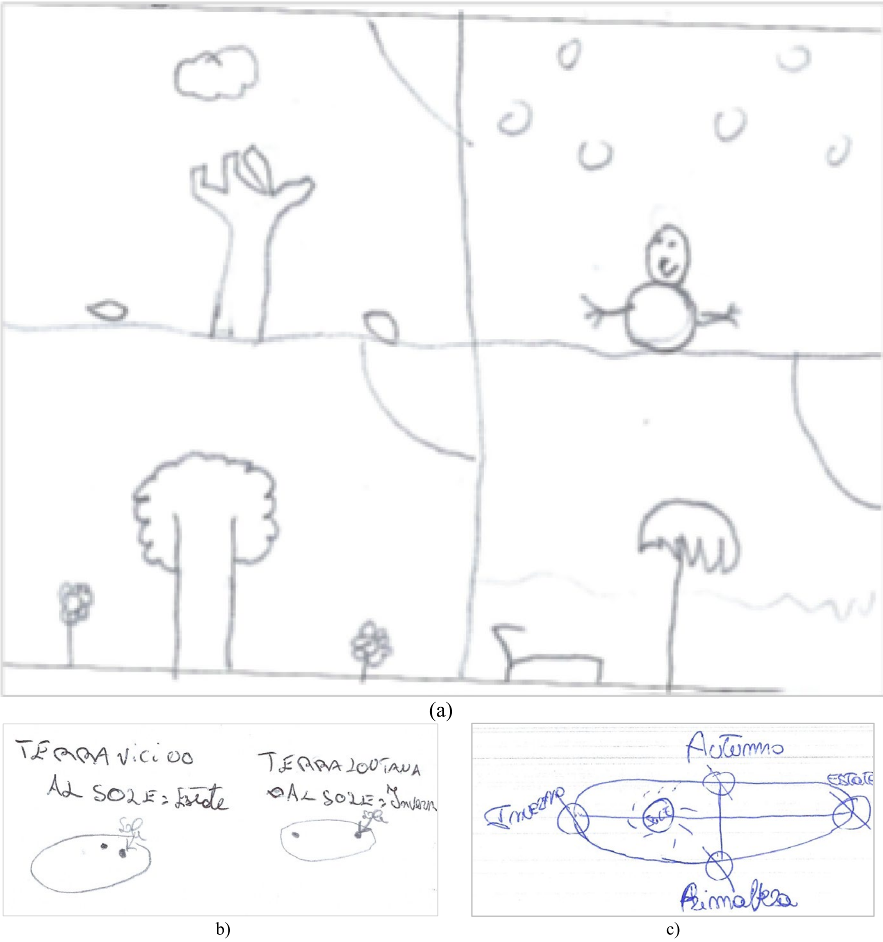

Fig. 1 Examples of students' drawings (**a**) naïve (**b**) distance-based (**c**) inclination-based. Translation of Italian text: b) Earth near the sun = summer; Earth away from the sun = winter; c) from left to right: winter, autumn, summer, spring

Combined Analysis of Drawings and Written Explanations

To quantitatively compare how the students under the different experimental conditions visually represented and explained the phenomenon of seasonal changes, we had to calculate a score that could take into account both drawings and written explanations. To this aim, we chose as statistical method the Multiple Correspondence Analysis (MCA). MCA is an extension of principal component analysis to categorical variables and is aimed to identify patterns of associations and oppositions between the different modalities of categorical responses (Blasius & Greenacre, 2014). Specifically, MCA translates such associations and oppositions into distances within a space. Such a process works by transforming categorical data into a form of binary data matrix, where each category is represented by a binary variable (present/absent). The result of this analysis is a set of factors, also known as dimensions, which represent the data in a reduced number of dimensions while preserving the relationships in the original data. Starting from the extracted factors, MCA analysis allows for calculations of the factorial scores for each category and for each subject. These scores can be used to visualize the data in a lower-dimensional space, often with the help of a biplot, which can reveal the associations between categories and the similarities between individual data points. In practical terms, the association between the modalities of the categories and the positive or negative values of the factorial scores allows the interpretation of the extracted factors (Di Franco, 2016). In our case, the categorical data were the student's responses to the draw-and-explain task, which were coded as described above with one out of the three drawing categories – *naïve; distance-based; inclination-based;* – and one out of the three explanations categories – *incorrect, partial, correct*, respectively. Being the modalities only three for both types of categorical data – drawings and explanations – in this study, we used only the first factor extracted from the MCA, which explained 74% of the variance in the data. After obtaining the corresponding factorial scores for each student, we checked through a 1-way analysis of variance (ANOVA) the association between the scores and the categories of drawings and explanations to collect validation evidence of the draw-and-explain task through method triangulation (Santiago-Delefosse et al., 2016). We found that positive factorial scores were significantly associated with both an "inclination-based" drawing and a correct explanation, while negative factorial scores were associated with both a "naïve" drawing and an "incorrect" explanation. More details on the relationships between the MCA factorial scores and categories of drawings and explanations are reported in the Supplemental material.

SCI Analysis

We scored the instrument as follows: true/false items were given 0.5 point for a correct response, while for multiple-choice items, 2 points were given for a correct answer choice. For both types of items, an incorrect answer was given 0 point. Maximum score was 7. Due to the different types of items used in the instrument, we report here the reliability of only the 6 true/false items. Reliability was 0.37 for the pre-test and 0.42 for the post-test. Such low values of reliability are expected for short instruments (less than 10 items) with only two answer choices due to the guessing contribution to error variance (Zimmerman & Williams, 2003).

Comparison of Students' Performances Across the Different Teaching Conditions

To answer our research question, we first performed a one-way ANOVA of the SCI scores in the pre-test to explore whether the students in the six teaching conditions had similar initial knowledge about the seasons. We limited the pre-instruction assessment to the SCI instrument since all the students in the sample had not been taught about seasonal changes before participating in the study, so we were not able to collect a sufficient number of drawings and explanations for the pre-test. Then, we compared through a series of independent samples *t-test* the scores in the first factor extracted from the MCA and the scores in the SCI instrument of the two groups in the "practice-based activity" and "no "practice-based activity", respectively. Then, we compared through an ANOVA the scores in the first factor extracted from the MCA and the scores in the SCI instrument of the three groups, "specially designed images", "textbook images" and "no images", respectively. Finally, we inspected the effects of the interaction between the two approaches – practice-based activity and images by performing a series of 2-way between-subjects ANOVAs using, as dependent variables, the scores in the first factor extracted from the MCA and the scores in SCI instrument, while the six teaching conditions were used as independent variables.

Results

Pre-Instruction Knowledge about Seasonal Changes

Mean scores of the pre-test SCI are reported in Table 2. After checking for outliers through inspection of boxplot and homogeneity of the variances through a Levene' test ($p = 0.403$), we performed an ANOVA, which showed no significant differences between the six groups, $F_{5,331} = 0.573$, $p = 0.721$, $\eta^2 = 0.009$.

Post-Instruction Knowledge about Seasonal Changes

The distribution of explanations and drawings categories in the post-test is reported in Table 2. The majority of the students (76%) in the "practice-based activity" condition produced an inclination-based drawing independently of the image condition whereas, for the "no practice-based activity" condition, only in the "specially designed images" group the majority of students produced an inclination-based drawing (63% vs. 35% and 19%, respectively).

Concerning explanations, the majority of students (59%) in the "practice-based activity" + "no images" condition gave a correct justification of seasonal changes. Conversely, the majority of the students in the "no practice-based activity" + "textbook images" and "no images" conditions (47% and 64%, respectively) gave an incorrect explanation. From the analysis of the MCA factorial scores, we note that the students in the "practice-based activity" + "no images" condition have the highest positive factorial score (0.48), in agreement with a higher frequency of "inclination-based" drawings (83%) and correct explanations (59%). The students in the "no practice-based activity" + "no images" condition have the lowest factorial score (–0.75), in agreement with a higher frequency of "distance-based" drawings (70%) and incorrect explanations (64%).

Then, after having performed a normality check through inspection of asymmetry and kurtosis of the scores' distribution (–0.597 and –0.815, respectively) and verified homogeneity of variances through Levene's test ($p = 0.106$), we calculated the differences between the mean factorial scores of the students in the "practice-based

Table 2 Pre- and post-test SCI mean scores, post-test drawings and explanations categories distribution and Multiple Correspondence Analysis (MCA) factorial scores for the six conditions of the study

Practice-based activity condition	Image condition	N	Pre-Instruction	Post-Instruction							
			SCI Average score [a] (SD)	Drawings (frequencies)			Explanations (frequencies)			MCA score Average [b] (SD)	SCI Average score [a] (SD)
				Naïve	Distance	Inclination	Incorrect	Partial	Correct		
"Practice-based activity"	*"specially designed images"*	55	4.55 (1.35)	1	8	46	17	18	20	0.36 (0.79)	5.91 (1.43)
	"textbook images"	56	4.68 (1.03)	1	21	34	14	18	24	0.24 (0.91)	6.10 (1.12)
	"no images"	59	4.75 (1.20)	1	9	49	16	8	35	0.48 (0.80)	6.09 (1.27)
"No practice-based activity"	*"specially designed images"*	54	4.81 (1.36)	10	10	34	17	18	19	0.01 (1.13)	6.28 (1.05)
	"textbook images"	60	4.46 (1.33)	9	30	21	28	15	17	−0.37 (0.98)	5.50 (1.39)
	"no images"	53	4.64 (1.39)	6	37	10	34	17	2	−0.75 (0.82)	5.41 (1.14)
Total		337	4.65 (1.28)	28	115	194	126	94	117	0.00 (1.00)	5.88 (1.28)

[a]Minimum score = 0; maximum score = 7

[b]Higher positive scores are associated to higher frequency of inclination-based drawings and correct explanations; lower negative scores are associated to higher frequency of naïve drawings and incorrect explanations. See Supplemental Material for more details

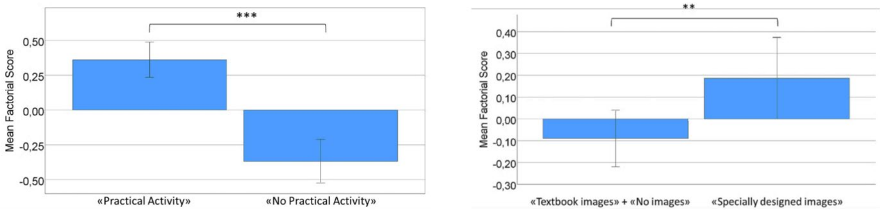

Fig. 2 **a** Mean post-instruction MCA factorial scores for the "practice-based activity" *vs.* "no practice-based activity" conditions. **b** Mean post-instruction MCA factorial scores for the "specially designed images" vs. "textbook images" and "no images" conditions. $^{**}p<.01$; $^{***}p<.001$

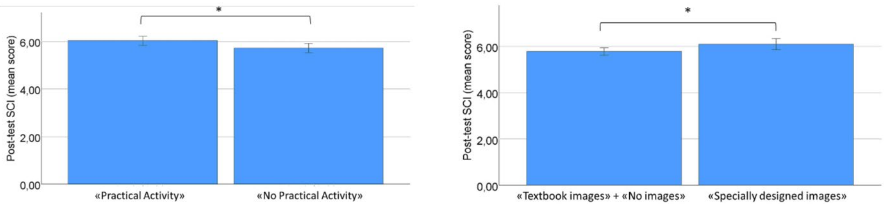

Fig. 3 **a** Mean post-instruction SCI score for the "practice-based activity" *vs.* "no practice-based activity" condition. **b** Mean post-instruction SCI score for the "specially designed images" *vs.* "textbook images" and "no images" conditions. $^{*}p<.05$

activity" and "no practice-based activity" conditions. Differences are statistically significant (see Fig. 2a), with the students in "practice-based activity" condition outperforming the students in the "no practice-based activity" condition, $t_{331}=7.327$, $p<0.001$.

Similarly, mean factorial score of students in the "specially designed images" condition is significantly higher than the score of the students in the other two images conditions (see Fig. 2b), $t_{331}=2.693$, $p<0.01$. In Table 2, we report also the post-test mean scores of the SCI. All groups increased their scores with respect to the pre-test, from an average of 4.65 points to an average of 5.88. Such result suggests the effectiveness of the activities in improving students' understanding of seasonal changes. However, the students in the "practice-based activity" condition performed slightly better than the students in the "no practice-based activity" (see Fig. 3a), $t_{331}=2.228$, $p<0.05$. Similarly, the students in the "specially designed images" condition scored higher than the students in the other two images conditions (see Fig. 3b), $t_{331}=2.208$, $p<0.05$. Notably, the mean scores of the post-test SCI are positively correlated with the mean MCA factorial scores, Pearson's $r=0.39$, $p<0.001$, thus suggesting an overall validity of our results.

Interaction Between Practice-Based Activities and Specially Designed Images

Before performing the 2-way between subjects ANOVA on the MCA factorial score, we verified that there were no outliers in our sample through a boxplot. Then, we checked for violation of homoscedasticity of error variances obtaining a non-significant result, $F_{1,\ 335}=0.467$, $p=0.495$. Levene's test for equal error variance was also not significant, $F_{5,\ 331}=1.832$, $p=0.106$.

Overall, for the MCA factorial score (Fig. 4a), we found a significant main effect of the "practice-based activity" condition, $F_{1,\ 331}=53.685$, $p<0.001$, $\eta^2=0.140$; of the "image condition", $F_{2,\ 331}=3.747$, $p<0.05$, $\eta^2=0.022$; and of the interaction between the two conditions, $F_{2,\ 331}=6.789$, $p<0.01$, $\eta^2=0.039$. Simple effects analysis shows that students in the "practice-based activity" condition outperformed students in the "no practice-based activity" condition in both the "textbook images" and "no images" conditions, $F_{1,331}=13.005$, $p<0.001$, $\eta^2=0.038$; $F_{1,331}=50.562$, $p<0.001$, $\eta^2=0.133$, respectively, while the difference in the "specially designed images" condition is only slightly significant and with a small effect size, $F_{1,331}=3.963$, $p=0.047$, $\eta^2=0.012$. Note that in the "practice-based activity" condition, the effect of the image condition is not statistically significant, $F_{2,\ 331}=1.039$, $p=0.355$, while for the "no practice-based activity" condition, the differences between the three groups who used different kind of images are statistically significant, $F_{2,\ 331}=9.224$, $p<0.001$. A post-hoc analysis show that this result is due to the statistically significant higher score of the students in the "specially designed images" condition with respect to the "no images" condition ($p<0.001$).

Concerning the post-test SCI, the assumptions of the 2-way ANOVA were also met with no outliers, homoscedasticity of error variances, $F_{1,\ 335}=1.070$, $p=0.302$ and equal error variance, $F_{5,\ 331}=1.608$, $p=0.157$. Figure 4b summarizes our findings for the post-test SCI. We found a significant main effect of the "practice-based activity" condition, $F_{1,\ 331}=4.964$, $p<0.05$, $\eta^2=0.015$ and of the interaction between the two conditions, $F_{2,\ 331}=6.128$, $p<0.01$, $\eta^2=0.036$. The image condition does not have a significant main effect on the post-test SCI score, $F_{2,\ 331}=2.466$, $p=0.086$, $\eta^2=0.015$. However, simple effects analysis reveals that, for the "textbook images" condition and for the "no images" condition, the differences between the post-test SCI scores of the students who performed the practice-based activity and of the students who did not performed the practice-based activity are statistically significant, with students in the "practice-based activity" condition outperforming the students in the "no practice-based activity" condition, $F_{1,\ 331}=6.786$, $p<0.05$,

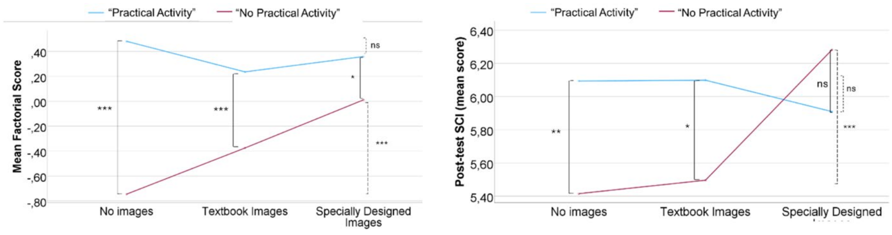

Fig. 4 **a** Mean post-instruction MCA factorial scores for the three images conditions and for the two practice-based activity conditions. **b** Post-test SCI mean score for the three image conditions and for the two practice-based activity conditions. Solid brackets indicate simple effects of the practice-based activity condition for each image condition, dotted brackets indicate simple effects of the different image condition for each practice-based condition. *$p<.05$; **$p<.01$; ***$p<.001$; ns: not significant

$\eta^2=0.020$; $F_{1, 331}=8.289$, $p<0.01$, $\eta^2=0.024$, respectively. Contrarily, for the students in the "specially designed images" condition, such difference is not statistically significant, $F_{1, 331}=2.452$, $p=0.118$, $\eta^2=0.007$. Notably, students who were exposed to the "specially designed images" and were in the "no practice-based activity" condition performed better than students who were exposed to the same type of images but were involved in the "practice-based activity" condition, although such a difference is not statistically different. Overall, for the "practice-based activity" condition, simple effects analysis shows no differences between the groups who used different types of images, $F_{2,331}=0.418$, $p=0.659$, $\eta^2=0.003$, while for the "no practice-based activity" condition, the differences across the groups are statistically significant, $F_{2,331}=8.076$, $p<0.001$, $\eta^2=0.047$. Post-hoc analysis shows that this result is due to the statistically significant higher score of the students in the "specially designed images" condition with respect to both "textbook images" and "no images" conditions ($p<0.01$).

Discussion and Conclusions

In this paper, we investigated the combined effect of two approaches to address seasonal changes, one based on practice-based activities and the other on the use of specially designed images. While previous studies were limited to a direct comparison of the effects of either practice-based or software-based activities on students' conceptual understanding (e.g., Kiroğlu et al., 2021), to the best of our knowledge, this is the first study that measures the effect of the interaction between two different approaches to teach seasonal changes. In the following, we discuss our results in relation to literature in astronomy education research.

First, collected evidence supports the conclusion that the students in the "practice-based activity" condition outperformed students in the "no practice-based activity" condition, independently of the type of image condition ("specially designed images"; "textbook images"; "no images"). While students in all the six conditions showed many alternative conceptions in the pre-test, in agreement with previous studies (Trumper, 2001b), the great majority of the students in the "practice-based activity" produced a drawing that featured the change of inclination of sunrays during the year and Earth's orbital motion and axis tilt as possible reason. Moreover, on average, about 46% of these students gave a correct written explanation of seasonal changes after the activities, thus suggesting a greater effectiveness of the proposed practice-based activities with respect to the other condition (22% on average of correct explanation). Our results align with findings obtained in previous studies that used practice-based approaches (e.g., Covitt et al., 2015; Plummer & Maynard, 2014; Türk & Kalkan, 2018). More generally, our findings support that contrasting different explanation of seasonal changes – the distance-based and the inclination-based – in a practice-based activities environment may favor students' modeling skills (Schwichow et al., 2020). Moreover, throughout such modelling process, the students can also learn how to identify the variables that describe the phenomenon, and how to apply the relationships between the variables of the model to different situations (Schalk et al., 2019).

Second, results show that the students in the "specially designed images" condition performed consistently better than the students in the "textbook images" and "no images" conditions in both the draw-and-explain task and the SCI questionnaire. This evidence confirms two general results: first, suitable graphical features (e.g., circular orbit, Earth's axis pointing in a constant direction) may help students to correctly connect the changing inclination of the sunrays from the Earth's viewpoint to the orbital motion and the tilted axis from a space observer's viewpoint (Sneider et al., 2011); second, combining different but related representations of the same phenomenon may help students understand how astronomical phenomena can be described in different frames of reference (Bekaert et al., 2022; De Paor et al., 2017). We will further discuss possible interpretations of this evidence below.

Third, we found a significant interaction of the two approaches on students' performance. Namely, while for the students in the "practice-based activity" condition the different images used did not significantly affect their performance, for the students in the "no practice-based activity" condition, the differences due to the use of different kind of images were statistically significant. Hence, the role of a teaching resource depends on the context in which it is used. In particular, the students in the "specially designed images" condition outperformed the students in the "textbook images" and "no images" conditions. We also found that when students in the "no practice-based activity" condition were taught with the specially designed images, their performance in the SCI questionnaire did not significantly differ from that of the students in the "practice-based activity" condition who were taught with the same images condition. Furthermore, in the draw-and-explain task, the difference in the factorial score between the students in the "practice-based activity" and "no practice-based activity" conditions who were taught with the specially designed images was lower than for the other two conditions. This evidence suggests that the special designed images helped the students in the "no practice-based activity" condition more than the textbook images or the simple text with no images at all. Therefore, to a certain extent, the specially designed images had the same effect as the practice-based activity in helping students contrast the distance model and the inclination model. Besides the different modality itself (practice-based activity vs. frontal lesson), some indications on why students in the "specially designed images" condition were not significantly disadvantaged by the lack of the practice-based activity may be put forth. First, in agreement with the semiotic theory, the graphical features of the used images, as the circular Earth's orbit and the two-panel structure were likely to provide students with *clues* that enabled them to understand why orbital motion and axis tilt affect seasonal changes. Specifically, these clues are likely to create a link between abstract concepts and visual elements (Schnotz, 2002) that may facilitate students in correctly modeling the represented phenomenon (Friedman et al., 2018). Second, the specially designed images used in this study are likely to promote cognitive processing to make sense of the relationships among and between celestial objects and reference frames in explaining seasonal changes (Mayer, 2017; Plummer, 2024). Finally, our findings also suggest that, independently on the "practice-based activity" condition, students in the "textbook images" condition did not perform significantly better than students in the "no images" condition, except in the draw-and-explain task, where there was a slight benefit to using any images over no images. This result confirms previous findings according to which visual representations in scientific texts may add comprehension challenges and lead to cognitive overload (McTigue & Flowers, 2011). This study also replicates the findings of studies about virtual representations to teach seasonal changes (Yu et al., 2015) and those of our previous studies (Galano et al., 2018; Testa et al., 2014).

Overall, the results of the present study suggest that teaching approaches that integrate practice-based activities with well-designed visual materials have the potential to further enhance students' understanding of introductory astronomy topics at middle and high school level considering both concept learning and reasoning aspects (Kim & Jin, 2022). As future steps, further research is needed to explore how these approaches can be adapted and implemented at different educational levels, e.g., primary schools, and how they can be combined with activities in out-of-school settings, e.g., planetarium, to develop students' understanding of astronomical phenomena. Secondly, future qualitative studies could provide valuable insights into students' understanding of seasonal change by exploring which specific visual materials or teaching approaches students prefer when studying this phenomenon. Similarly, further research is warranted to explore how students with different spatial reasoning skills, such as mental rotation, respond to the proposed approaches and, conversely, whether and how the proposed approaches might enhance such skills. Finally, future studies might also investigate how the combination of practice-based activities and specially designed images can foster students' understanding of other familiar astronomical phenomena, such as day/night cycle, lunar phases, and eclipses.

Limitations of the Study

The present study has the following limitations. First, the students in the "practice-based activity" could have been advantaged by a greater peer interaction during the measurements with the solar panel. Second, we tried to maximize the control on the six different conditions by letting the first author leading the 6-h activities, albeit with an active support by the teachers in their classes, in order to not substitute them for the topics that they usually teach. Admittedly, this design has also a limitation because it reduces the ecological validity of the study in that different teachers could have enacted the same resources differently (Fazio & Gallagher, 2019; Lin et al., 2022). Third, external validity of the results of our study is limited by the fact that the three schools that answered to the call are usually involved in implementing research-based curriculum innovations and regularly participate in university outreach programs. The generalizability of our findings is also limited by the fact that only students with parental consent participated in the study and by the organization of the schools, which allowed us to perform the randomization of the different experimental conditions only at the class level. Fourth, to assess students' knowledge of the seasons, we used a concept inventory with only eight items, six of which were in a true/false format. While this format was advantageous to reduce the impact on school organization, it limits the generalizability of the findings due to the low reliability of the probe. We are currently validating a new two-tier multiple-choice instrument to address this issue. Finally, while the a-priori power analysis supported that our sample was sufficiently large to detect a moderate effect size of the main effects and of the interaction between the "practice-based activity" and the "images" condition, a larger sample could have revealed also smaller effects not detected in the present study.

Appendix

Seasons Concept Inventory (SCI)

The main factor for which summer and winter alternate is:

(a) the distance between Sun and Earth changes during the year, so the incidence of solar rays on the Earth's surface varies
(b) the inclination of the Earth's axis with respect to the orbit plane changes during the year, therefore the incidence of the solar rays on the Earth surface varies
(c) Earth's axis direction in space changes during the year therefore the incidence of the solar rays on the Earth's surface varies
(d) Earth's position along its orbit changes during the year, therefore the incidence of the solar rays on the Earth's surface varies

The reason for which in Italy during summer is hotter than in winter is that during summer

(a) the Earth is closer to the Sun and day lasts more than in winter
(b) the inclination of Earth's axis changes
(c) solar rays are less inclined and the day is longer
(d) the Sun produces more energy

Indicate whether the following statements are true or false.

1. The Sun produces more energy in summer than in winter.
2. The energy absorbed by a surface illuminated by a light source is maximum when the light strikes the surface perpendicularly.
3. The incidence of the Sun's rays on the earth's surface varies over the year.
4. The Earth's surface absorbs energy from the Sun.
5. The Earth's axis of rotation is tilted with respect to the plane of the Earth's orbit.
6. Earth's axis of rotation throughout the year remains parallel to itself.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10763-025-10549-8.

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Data Availability Dataset is available from corresponding author upon reasonable request.

Declarations

Ethical Approval The authors declare that the research with human subjects described in this study was conducted in accordance with the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects and the ICMJE guidelines on Protection of Research Participants. Approval by local research ethics committee was not required at the time when the study was carried out since no medical treatment was carried out and participants were anonymized.

Ethical Declaration The authors declare that:

- The manuscript is not under review in other journals for simultaneous consideration.
- The submitted work is original and has not been published elsewhere in any form or language (partially or in full)
- The new work is an expansion of previous work, and we clearly indicate the previous materials that have been used in the present work
- No data, text, or theories by others have been presented in the present work as if they were the author's own
- Permissions secured for material that is copyrighted were obtained

Consent to Participate and Consent to Publish Informed consent forms were signed before the beginning of the activities by the students' parents for study participation and research purposes, in order to fulfil the requirements of Italian law. Refer to the following document for the Italian regulation of this matter:

https://www.garanteprivacy.it/documents/10160/0/Regolamento+UE+2016+679.+Arricchito+con+riferimenti+ai+Considerando+Aggiornato+alle+rettifiche+pubblicate+sulla+Gazzetta+Ufficiale++dell%27Unione+europea+127+del+23+maggio+2018

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