The Parallel Globe: a powerful instrument to perform investigation on Earth's illumination

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Abstract

Many researches document difficulties by learners of different ages and preparation in understanding basic astronomical concepts. Traditional instructional strategies and communication media seem not effective in producing meaningful understanding or even induce some misconceptions and misinterpretations. In line with recent proposals of pedagogical sequences and learning progressions about core concepts and basic procedures in physics and astronomy education, in this paper we suggest an intermediate, essential, step in the teaching path from the local geocentric view of the Earth-Sun system to the heliocentric one. At this aim we present data collected along a day and a year through an instrument we call "Parallel Globe", a globe positioned locally homothetic to the Earth we live on. Some analyses are suggested, in particular about the phenomenon of illumination of the Earth and its variations, consistent with the proposed instructional objectives.

INTRODUCTION

Since 1974, hundreds of researches on astronomy education have been performed involving students, teachers and museums' visitors from many countries and different education levels. They showed that alternative conceptions and shortcomings in understanding basic astronomy concepts were common, widespread and present even in the highest levels of education [1, 2, 3, 4, 5]. Findings also suggested that misunderstandings are not deeply modified by conventional teaching [6] or can be even induced by traditional models, textbooks and images [7]. Consequently, one of the current challenges for the astronomy education community is to develop innovative methods and proposals to prevent or redress those misunderstandings.

Recently, some educational sequences and learning progressions have been proposed about basic astronomy [8, 9, 10] taking into account the general difficulties in understanding astronomy and devoting attention not only to core concepts but also to scientific procedures [11, 12]. These approaches share some common features as the importance to start the teaching pathway with sky observations above the local horizon; to use multiple representations (e.g. three-dimensional models, body plays and gestures) to represent and interpret the data; to move from the Earth-based to the heliocentric frame of reference using hands-on, kinaesthetic, concrete modelling strategies joined with computer simulations [13, 14].

Although the findings were encouraging and the approaches more effective than the conventional ones, further researches have been recommended.

As Italian researchers in math, physics and astronomy teaching, we found that to promote a meaningful astronomical knowledge it is essential to introduce an intermediate step between the local observations and the interpretation in the heliocentric reference frame. With this aim, we designed an innovative use of the globe that can make it an effective instrument to observe the Earth’s illumination in real time and from the place where the observer is: the “Parallel Globe” [15]. This paper is devoted to the description of this instrument, its uses and the implications in teaching basic astronomy.

Preparing the instrument

The first action that has to be done to prepare the instrument is to select an outdoor site illuminated by the Sun as long as possible during the day and throughout the year. Then, the traditional globe has to be unlooked from its fixed stand and placed in the selected site on a new support in a way that:

- the observer’s country in on the highest point of the globe
- the globe axis is on the local meridian plane

Using some adhesive stuff (like modelling clay, suckers), many sticks (nails or pins) have to be fixed perpendicular to the globe's surface along the Equator, the Tropics and the observer’s meridian and parallel. Each stick represents a person standing on the Earth in a vertical position at that location. If the globe’s position and orientation is taken fixed, the globe is illuminated by the Sun as the Earth itself and the sticks are illuminated by the Sun as local vertical gnomons (Figure 1).

Once the Parallel Globe is oriented: the stick representing the observer is parallel to observer’s standing direction; the plane tangent to the globe in observer’s position is parallel to her horizontal plane; the globe’s axis is parallel to Earth's one. For those reasons, we called the instrument Parallel Globe. In the literature, the same instrument was introduced with different names: the geosynchronous globe [9] and the day/night globe [16].

Figure 1. The Parallel Globe at Sesto San Giovanni (9° 14' 00'' East, 45° 32' 00'' North), near Milan (Italy)

Planning and carrying out investigation

We suggest to observe the Parallel Globe along the Equinox and Solstice days and, at least, three times a day: before, during and after the local solar noon. We also suggest to take pictures of the globe from different points of view and from different distances all along the investigation time (Figure 2). This plan was developed thanks to the participation at the Globo Local Project, an international project designed (by two of the authors) to promote the use of the Parallel Globe around the world [16]. Obviously, other investigation plans could be designed depending on the available time and on the aim of the teaching intervention. In general, the ability to get astronomical information from this tool increases with the use and the familiarity with it.

For long-term investigations (one year or more) or sharing data with observers in other countries, a digital archive is strongly recommended. To have suggestions you can visit the public archive available at the web site www.globolocal.net, built in 2011 in occasion of the Globo Local Project.

Figure 2. Snapshots taken about 10 am in June Solstice by North (a), East (b), South (c) and West (d).

Analysing the data

Once the data are available, they can be analysed looking at two variables: the terminator position across the globe surface and the pattern of sticks' shadows. In the first case, we are looking at the Earth as a whole, in the second one the attention is on particular conditions of some points of its surface. Analysing the time evolution of those variables, we can get information about the changes of lit/shade hemispheres across Earth surface and changes of Sun pathway at different latitudes.

In the following, we present the main results that can be obtained by analysing snapshot, daily and annual data[1].

Snapshot observation

Instantaneous observation of the Parallel Globe allows to identify the countries where currently it is day or night, the meridian at which the Sun is in transit (local solar noon) and where *night to day* or *day to night* transition is just happening (Table 1).

[1] We have to mention that the data used in the tables were collected by Sabrina Rossi and Daniela Calò at the Giocheria Laboratori, an educational municipality of Sesto San Giovanni, near Milan (Italy), in 2012 June Solstice and Equinoxes

It also gives the opportunity to get simultaneously information about the Sun position along the parallels (in particular along the Tropics, the Equator and the observer's one) or the meridians. In particular, it allows to infer how the Sun position at the local solar noon changes in function of the latitude and to find the point where the Sun is currently culminating at the Zenith (Table 2).

Daily observation

Daily observation of the Parallel Globe gives the opportunity to visualize how the lit/shade hemisphere changes along the day and, consequently, the places going into day or night. It also allows to observe how the local illumination conditions changes from one point to another and how the Sun pathway depends by latitude (Table 3). Finally, it gives the chance to calculate the day-length in function of the latitude simply looking at the lit part of the corresponding parallel (Table 4).

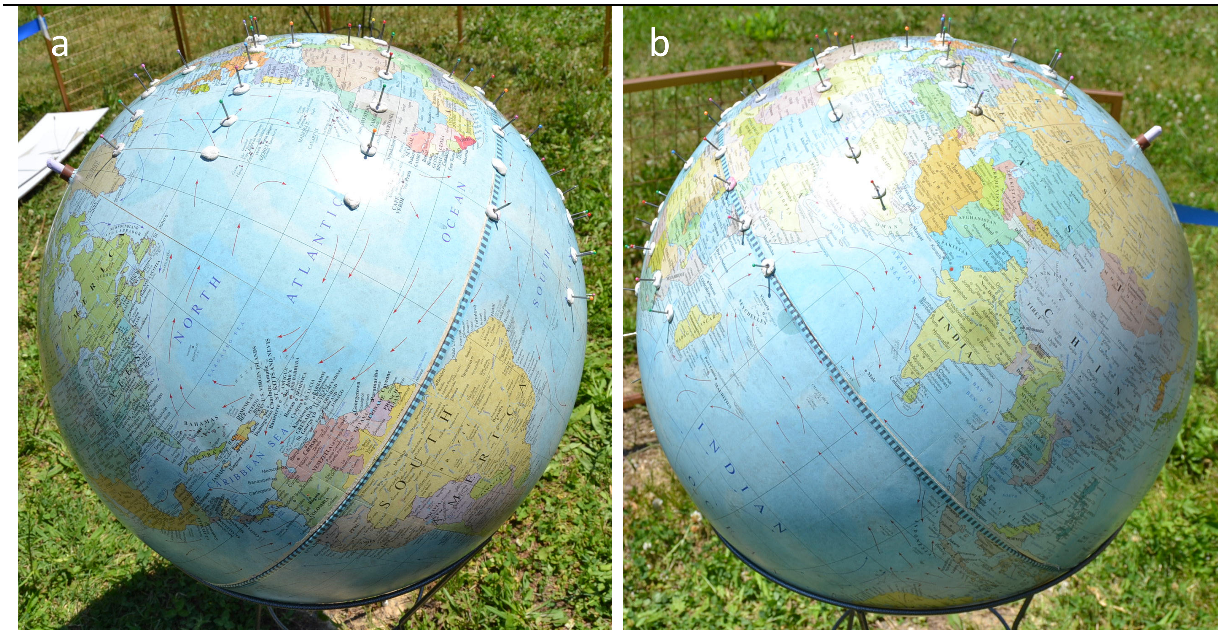
Annual observation

Annual observation gives the opportunity to visualize the annual cyclical movement of the terminator across the Earth's surface and the resulting changes of the day-length and of the observed Sun path at different latitudes. In particular, it allows to find the Earth's zones where day or night can last 24 hours (Table 5) and where the Sun can culminate at the Zenith position (Table 6).

Table 7 summarizes some of the results can be obtained observing the Parallel Globe during the Equinox and the Solstice days: the terminator position, the parallel where the sunlight strikes perpendicularly the surface, the latitude-changes of the day-length and the Sun altitude at the local solar noon.

Table 1

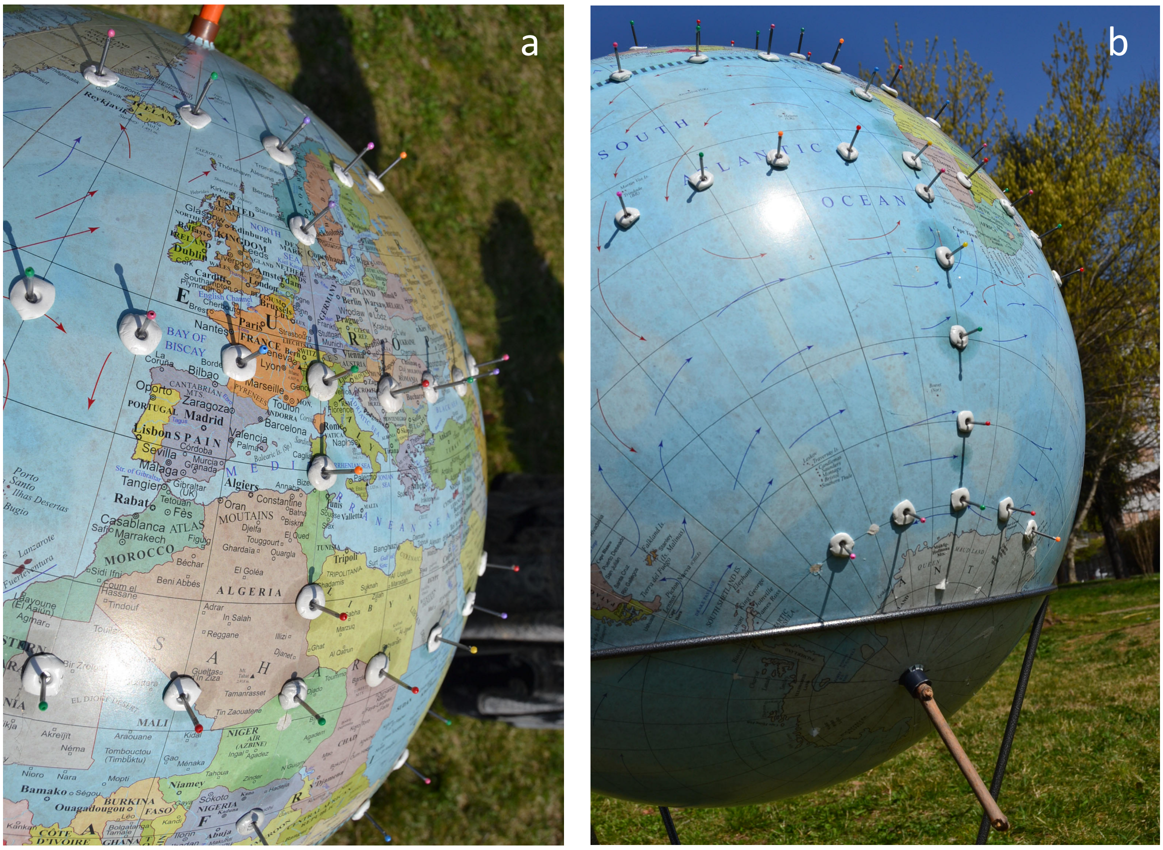
Terminator and day to night/ night to day transition along the globe



Looking at the globe as a whole by some distance, you can observe the line separating the sunlit hemisphere from the shaded one. It shows the current position of the Earth's terminator and, consequently, the countries where the Sun is locally rising (a) or setting (b). It limits the countries where the Sun is over (lit part) or under (shaded part) the local horizon. Looking at the hemisphere in full sun, you can find the halfway meridian, corresponding to the longitude where the Sun is currently culminating. Looking at the same parallel, the shadows are symmetric with respect to the noon meridian.

Table 2

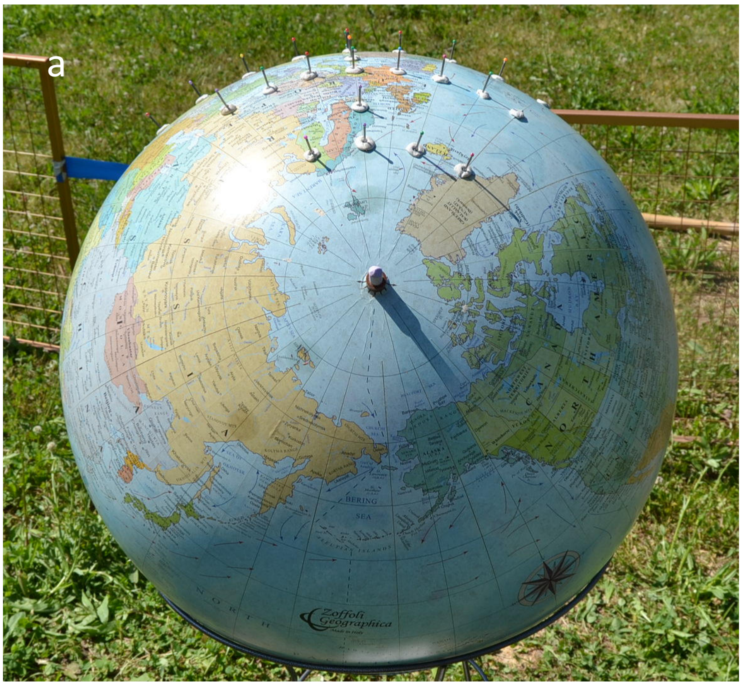
The solar transit over the local meridian

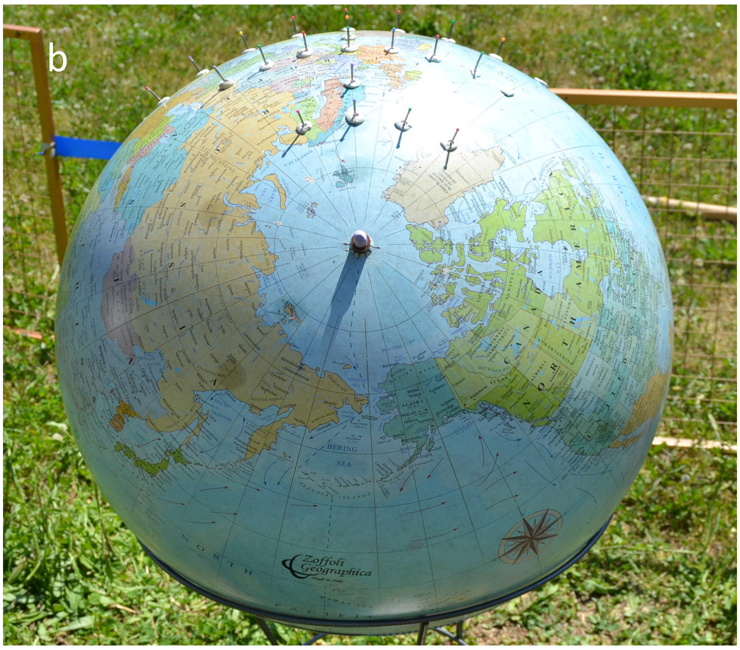


Looking at the size and direction of each stick' shadow, you can get information about the Sun's position for the observer represented by that stick . Observing the instrument at the local noon, all the sticks placed along the local meridian cast their shadows along the meridian itself. Moreover, there is a stick without shadow separating the ones with shadows directed toward the North Pole (a) or South Pole (b). It individuates the latitude where the Sun is culminating at Zenith and separates the latitudes where the Sun culminates above South (a) or North (b) respectively. Looking at the same parallel, you can see that the sticks’ shadows are symmetric with respect to the local meridian.

Table 3

The daily movement of the Earth's terminator and the latitude-specific day-length differences

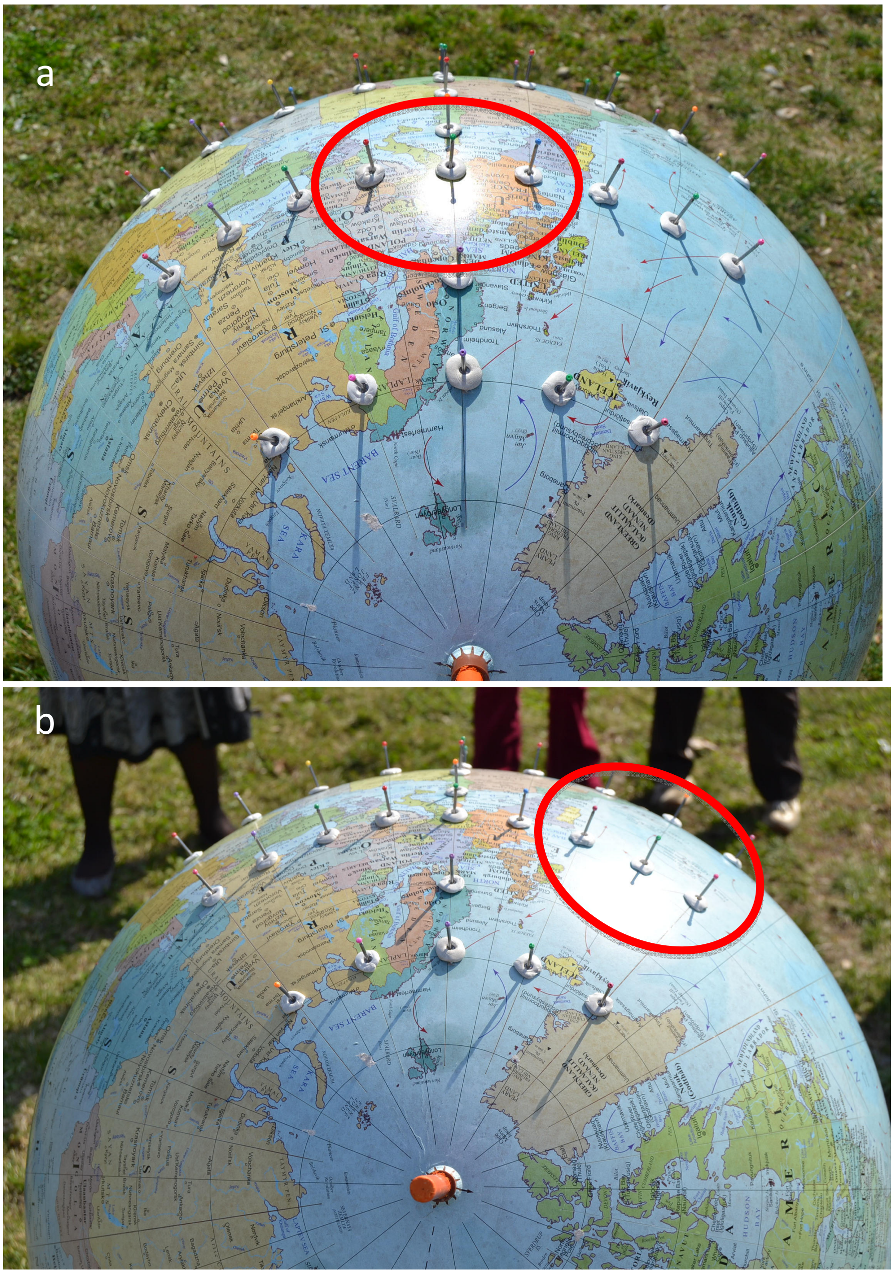




Looking at the Parallel Globe during the June Solstice, before (a) and after (b) noon by North, you can see that the terminator moves from East to West, 15°/hour, remaining tangent to the same pair of parallels for almost all the day. Consequently, the angular amplitude of the lit part of each parallel remains constant along the day as well as the day-length at fixed latitude. You can calculate it dividing the measured angular amplitude of the illuminated part of the corresponding parallel by 15°. For each day, you can find the latitudes where the day-lenght is less, equal of more than 12 hours. In particular, we can find the latitudes where the Sun do not ever set or ever rise along the day.

Table 4

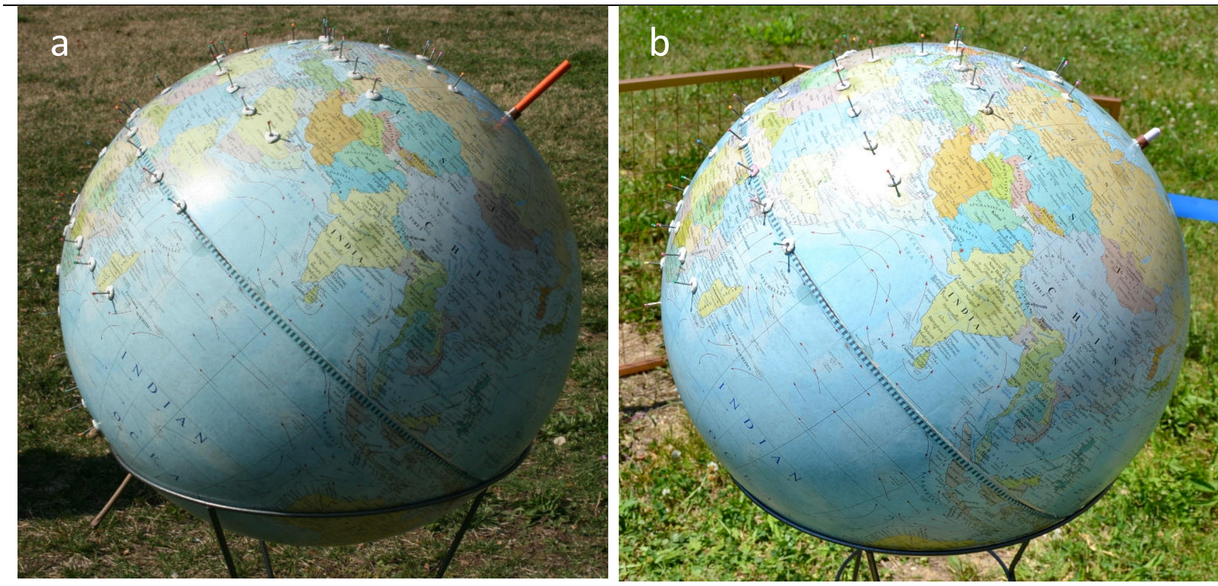
The solar transit over different meridians and the latitude and longitude-specific solar paths' differences



Recording the pattern of sticks' shadows during the June Solstice, at noon (a) and after noon (b) by North, you can see that it moves 15 °/hour. Indeed, comparing the shadows along the observer's parallel before, during and after local solar noon, it can be seen that the pattern of shadows cast by sticks along one parallel (same latitude and different longitude) at a certain time, is identical to the shadows' pattern produced by one stick along that day. Therefore, all observers on the same parallel see the same path of the Sun above their (astronomical) horizon and have the same number of light hours.

Table 5

The annual movement of the Earth's terminator and the annual changes in latitude-specific day-length



Observing the Parallel Globe during the year, you can see that the pair of parallels at which the terminator is tangent changes from day to day in a continuous way and it is always between the Polar Circles and the Poles.

In particular, it is possible to observe that:

• at the December Solstice, the terminator is tangent to the Polar Circles, the whole Arctic area is in shade and the Antarctic one is illuminated

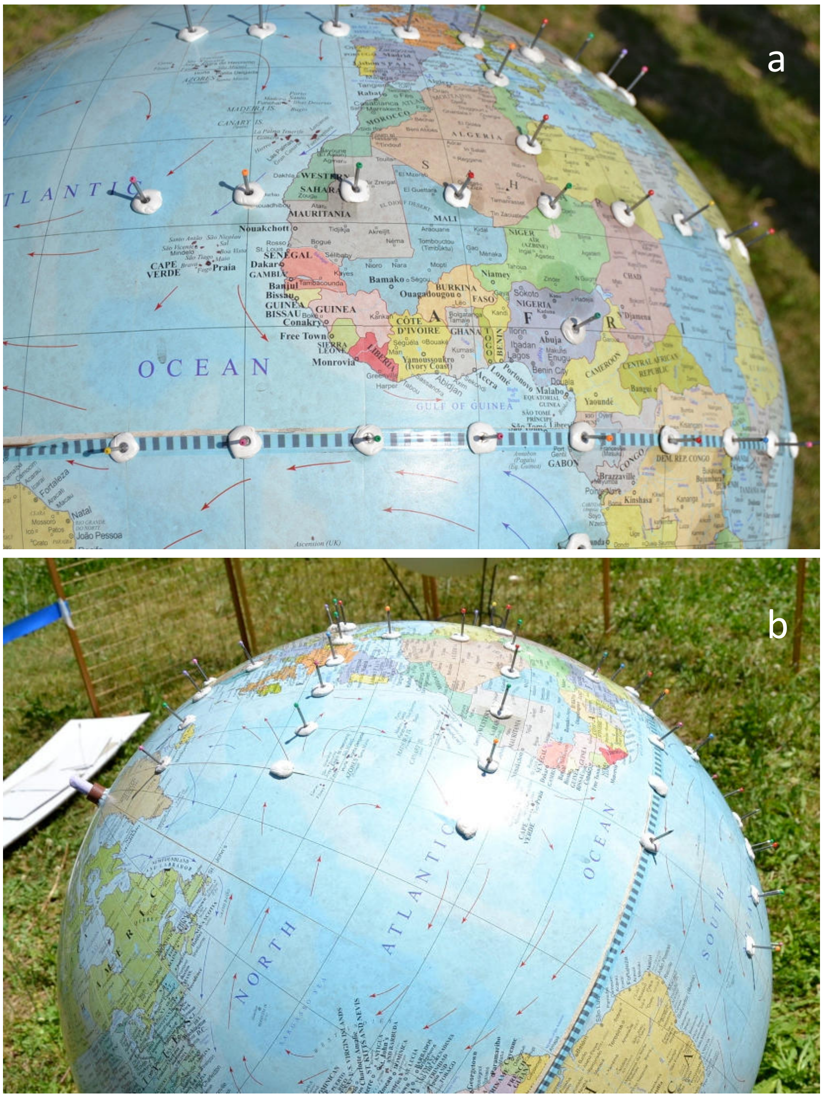
• at the March and September Equinoxes, the terminator passes through the poles (a)

• at the June Solstice, the terminator is tangent to the Polar Circles, the whole Arctic area is illuminated and the Antarctic one is in shade (b).

You can note that the Equator is always half enlightened and consequently the day-length at the Equator is always 12 hours. You can also see the annual cyclic variation of daytime at each latitude.

Table 6

The annual changes in latitude-specific solar path



Recording the sticks shadows' patterns during the year, you can find the parallel where the Sun culminates at the Zenith. It results that the parallel changes from day to day in a continuous way and it is always between the Tropics.

In particular, you can note that:

- at the December Solstice, the Sun culminates at the Zenith for observers on the Tropic of Capricorn
- at the March and September Equinoxes, the Sun culminates at the Zenith for observers on the Equator (a)
- at the June solstice, the Sun culminates at the Zenith for observers on the Tropic of Cancer (b)

Table 7

Summary of some basic astronomical information obtained by using the Parallel Globe

	March Equinox	***June Solstice***	***September Equinox***	***December Solstice***
Position of the Earth' terminator	Through the Poles	Tangent to the Polar Circles; the Arctic Polar zone is fully enlightened and the Antarctic Polar zone is fully shaded	Through the Poles	Tangent to the Polar Circles; the Antarctic Polar zone is fully enlightened and the Arctic Polar zone is fully shaded
Parallel where the Solar radiation is perpendicular the Earth' surface	Equator	Tropic of Cancer	Equator	Tropic of Capricorn
Day-length	12 hours, latitude independent	24 hours in the Arctic Polar zone 12 hours at the Equator 0 hours in the Antarctic Polar zone	12 hours, latitude independent	24 hours in the Antarctic Polar zone 12 hours at the Equator 0 hours in the Arctic Polar zone
Sun altitude α ***at local solar noon***	$0° \leq \alpha \leq 90°$ S Northern Hemisphere $\alpha = 90°$ Equator $0° \leq \alpha \leq 90°$ N Southern Hemisphere	23° 27'S $\leq \alpha \leq$ 90°S moving from North Pole to Tropic of Cancer $\alpha = 90°$ Tropic of Cancer $0° \leq \alpha \leq 90°$N moving from South Pole to Tropic of Cancer	$0° \leq \alpha \leq 90°$ S Northern Hemisphere $\alpha = 90°$ Equator $0° \leq \alpha \leq 90°$N Southern Hemisphere	$0° \leq \alpha \leq 90°$ S moving from North Pole to Tropic of Capricorn $\alpha = 90°$ Tropic of Capricorn 23° 27' N $\leq \alpha \leq$ 90° N moving from South Pole to Tropic of Capricorn

Implications for teaching

As described in this paper, the Parallel Globe allows to visualize how the Earth's illumination changes in time and across its surface. It also allows to construct the relationship between the local Sun pathway and the way the Sunlight beam reaches the observer's position. Therefore, the Parallel Globe can be effective in overcoming seasons' difficulties and help students to move in a meaningful way toward the heliocentric interpretation of local observations [17].

In the teaching pathway, the Parallel Globe can be used side by side with: long-term investigation of the Sun over the local horizon; systematic use of software offering the opportunity to change position and date/hour in looking at the sky (e.g. Stellarium); connections with other schools around the world sharing experiences [18, 19, 16]. In this way, the learners' phenomenological knowledge greatly enriches and a global vision can be created without loosing local perspective and specificity. In this perspective, we designed a three steps learning progression introducing the phenomenon's geocentric point of view beside the local one and before moving to the traditional heliocentric interpretation. Based on that progression, we implemented pedagogical sequences in some primary and middle school classes and in primary teachers' University courses [20, 21, 22].

In all cases, we devoted particular attention to epistemological and historical dimensions of knowledge construction and, in particular, to the complex relationship in physics between observations, interpretations/experiments and theories [23, 24, 25]. At first sight, indeed, the Parallel Globe seems to suggest a geocentric interpretation of the Earth's illumination phenomenon, like any Earth-based observation. However, the interpretation of the terminator's movement needs to take into account two basic ideas of physics: *relative movement* and *reference frame*. Indeed, as clearly stated by Copernicus:

"Every observed change of place is caused by a motion of either the observed object or the observer or, of course, by an unequal displacement of each. For when things move with equal speed in the same direction, the motion is not perceived, as between the observed object and the observer, I mean it is the Earth, however, from which the celestial ballet is beheld in its repeated performances before our eyes. Therefore, if any motion is ascribed to the Earth, in all things outside it the same motion will appear, but in the opposite direction, as though they were moving past it. Such in particular is the daily rotation, since it seems to involve the entire universe except the Earth and what is around it." [26].

Becoming aware of the reasons why the scientific community has chosen to describe and interpret the phenomenon of Earth's illumination in the heliocentric reference frame means becoming aware of the true intellectual conquest and the cultural revolution started by Copernicus and Galileo.

Acknowledgment

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