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TASTE

Teaching Astronomy at Educational Level

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(2020-1-IT02-KA201-079528)

Working with 3D models

during a visit at the planetarium/science center

Teacher's guide

Activities and Exercises for geocentric and allocentric views

Introduction

The lesson plan presented below is the teacher's guide for a plan of a 90-min program, part of the TASTE project, to be submitted to the group of students visiting the science center/planetarium.

The program uses two of the 3D models developed for TASTE Erasmus+ project's IO10, namely the "parallel globe" and the "bottle globe" and is an adaptive synthesis of the teaching units developed during the project.

The activities and exercises included in this lesson plan aim to help students to understand their place on Earth and visualize the Earth-Sun position inside the celestial sphere that surrounds us. It also gives students the chance to experience a geocentric and an allocentric point of view, helping them to acquire a correct model to interpret and explain the daily and annual Sun and stars' apparent motions and the associated phenomena.

Along with the main goals, the activities and exercises have been chosen taking into consideration various limitations (such as school time and space constraints, and weather conditions).

The activity consists of two parts. On a clear day, the first part of the activity (Part A) can be performed outside, in an open space that receives direct sun illumination. If the weather conditions do not allow this, with specific adjustments the first part can be performed inside, in a space resembling a classroom. The second part of the program (Part B) is designed to be performed inside.

Part 1 - A terrestrial point of view – Working with the parallel globe (30 min)

Background information

All globes give the idea of the Earth, where anyone can figure a part of humanity standing upright, with all the others tilted or upside down and this view is like an extra-terrestrial point of observation, from outside the Earth, with a privileged direction (i.e.: the terrestrial North Pole direction).
The following activities and exercises will allow the students to have the point of view of every terrestrial on the Earth, standing on the ground, with different orientations, in different locations on Earth, with different latitude and longitude.

The parallel globe is a globe liberated from its traditional support and free to assume different orientations depending on the place where we live. In each location it has to be oriented so that the direction of the globe axis is set parallel to the terrestrial one and the horizontal plane under the observer's feet is parallel to the tangent plane to the globe in its upper point. In this way, the observer's location faces up on the globe and its poles point toward north/south celestial poles as locally seen. From the mathematical point of view, this globe is homothetic to the Earth in Space.

Working with small Styrofoam balls and the parallel globe the students find their place on Earth, they locate the local horizon and the meridian as well as the cardinal points at their location using the polar star. The parallel globe can be adjusted so that your location on Earth is seen as the topmost location on the globe. This means you have set the parallel globe for your Earth's position. To express this, we will write that you have set the parallel globe for your Earth's position. This way, the parallel globe is oriented as the Earth in your surroundings. In the same way you will be able to set the parallel globe for one observer at the North Pole or on the equator.

Materials

- Styrofoam balls, with a diameter 20 to 30 cm.

- Toothpicks in different colors

- The parallel globe

- Magnetic sticks

- Cardboard cut into circular disks, diameter 10 cm, with the cardinal points on them.

Activity 1: Your place on Earth (15-20 min)

Part 1: Where do you stand?

In this part the students work with the small Styrofoam balls.

- Give each student a Styrofoam ball and a toothpick. The Styrofoam ball represents the Earth. The toothpick represents the student.

- Give students the following instructions:

A) Hold the Earth with your hands and place the toothpick on it to represent your current position. *(The toothpick must be placed on the top of the ball).*

B*) Now look around you and extend your arm to show where you think Finland is.*

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C) To which direction do you have to move to go to Finland? to Australia? *(Downwards).*

Part 2: Place yourself on Earth

In this part, you introduce the parallel globe. The students are working with their small balls and with the parallel globe when they are asked to.

- Place the parallel globe with the North Pole upwards, the South Pole downwards, and its axis vertical.

- Ask students to keep their small Earths in their hands so that they have the North Pole up and the South Pole down. Ask them to signal the poles with toothpicks.

- Ask them to place toothpicks to spot where they think Heidelberg, Thessaloniki, Helsinki, Tokyo, Cape Town, and Sidney are on Earth. Do the same in the parallel globe with the magnetic sticks.

Fig. 1a – The parallel globe for a place in the northern hemisphere.

- Ask students to keep their small Earth in their hands, placing themselves at the current location. Do the same with the parallel globe.

Explain that to visualize how the position on the Earth is for any observer in any location, with the observer always standing upright, the parallel globe must be set so that the observer's location is on the top of the globe.

Fig. 1b – The parallel globe for a place in the southern hemisphere.

- Now for the current location, ask a student to hold the cardboard disk underneath the stick to visualize the local horizontal plane. Do the same for other locations.

Fig. 2 – The parallel globe and the local horizontal plane

- Ask the students to identify the local horizon and the cardinal points in the real environment.

Part 3: Shadows, Sun and Geography

* If the weather allows it and the activity is performed outside, around noon (when the sun is culminating at your location) using the parallel globe and observing the direction of the shadow casted by the observer (the shadow of the stick) it is easy to identify the N-S direction and the cardinal points.

Extra content

Being in an open space outside and having the parallel globe placed for the current location, the globe and the stick on the top (representing you) are reached by the Sun exactly as on the real Earth, you and your students receive the sunrays in your location. Watching the parallel globe, you and your students are watching yourself on the globe in your exact position on the Earth with respect to the sun ray's direction. The lighted region on the globe represents all the places on Earth with daylight (i.e.:it is day for those places). The shadowed region on the globe represents all the places on Earth where it is night. Making a full rotation of the globe from west to east you can see how your current place passes from day to night.

- Place the parallel globe for your current location and put sticks along a meridian.

- Place the globe so that the meridian faces the Sun (it corresponds to the real meridian).

Fig. 3: Sticks/observers and their shadows along the meridian and various parallels.

* If the weather doesn't allow it and the activity is performed inside, for this part of the activity you can use and project the following pictures, explaining to the students that the photos were taken) on a clear, sunny day around noon.

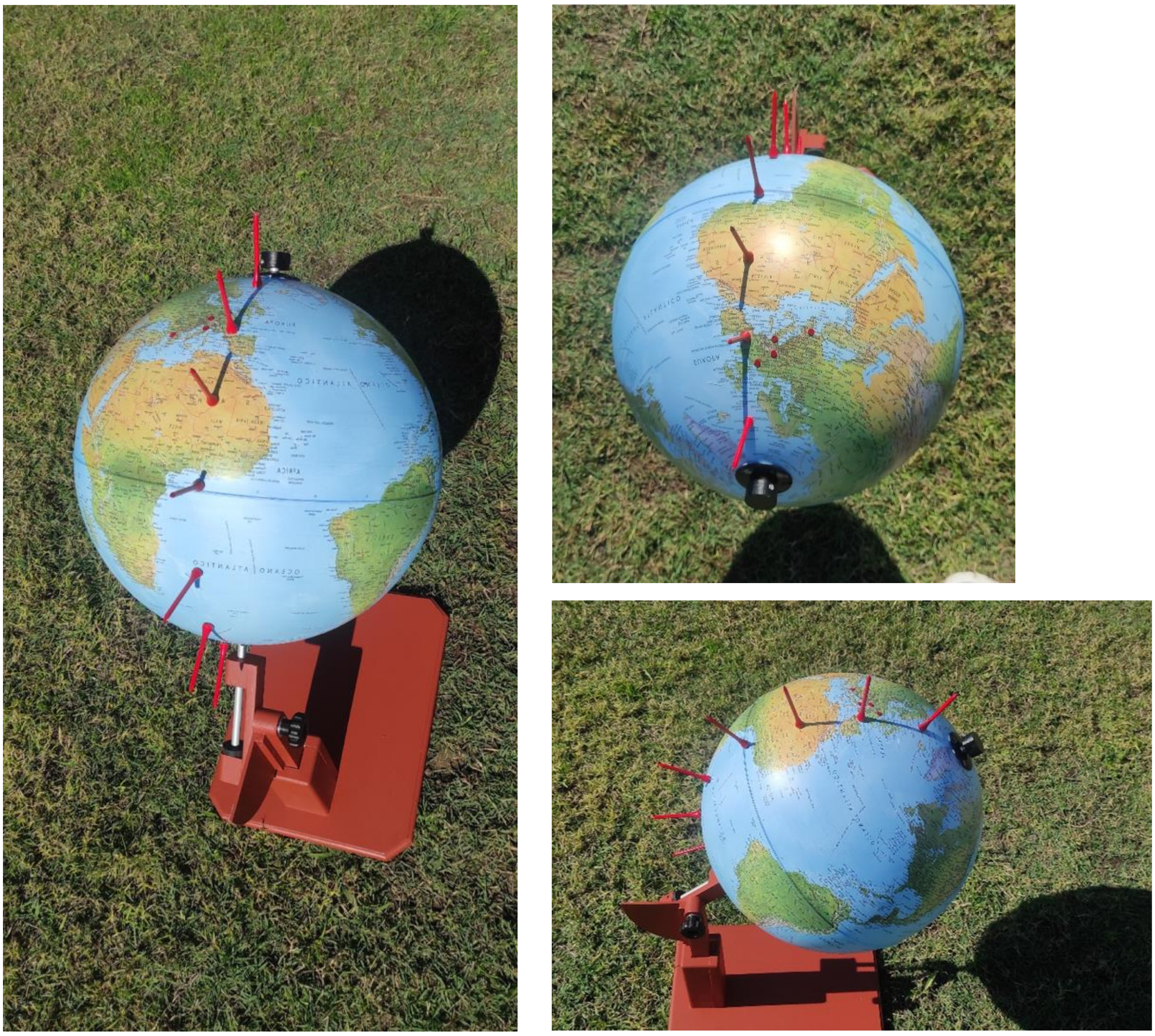


Fig. 4: Observers and their shadows along the meridian, during true noon.

- Ask students to observe on the globe the shadows cast by various observers on Earth (the sticks) and answer the following questions:

- *Are the shadows all alike? (No)*

- *How are the shadows of the sticks different from each other and why? (The length and the direction of the shadows are different. The shadows keep their direction in the same hemisphere but become shorter as we move from the North Pole to the equator.*

- *Can you identify on the parallel globe and on your surroundings the directions of the four cardinal points for your current location? (The direction of the shadows along the local meridian shows the N-S direction).*

Extra content

The Sun position in the Solar System doesn't change. What changes, at any time, is the angle at which you see the Sun from the place you are. The shadows depend on the position where we see the Sun in the sky (sun elevation). The higher the latitude the lower is the Sun position in the sky as seen from this location and the longer is the shadow cast by the stick).

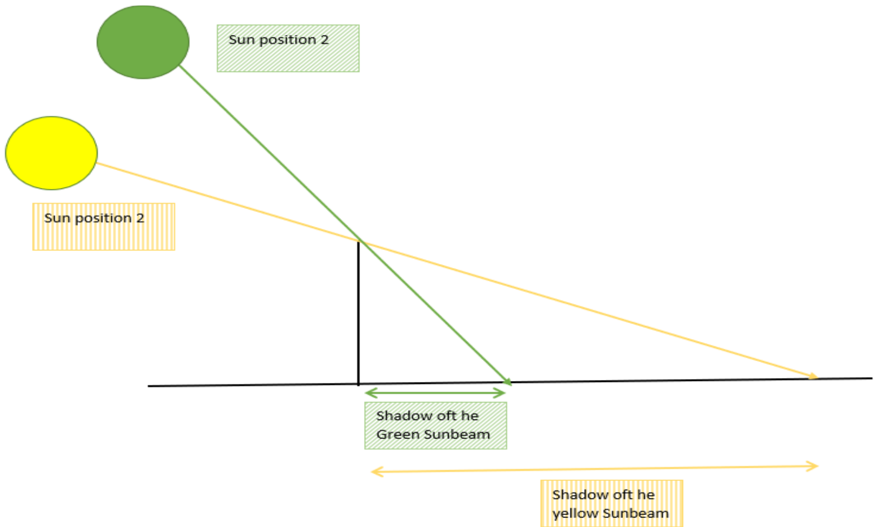


Fig. 4: the shadow cast by the sticks at different latitudes on the same meridian. Seen from aside.

In an open space around noon, the direction of the shadows helps us to orient ourselves. They show the N-S direction, pointing towards north. Knowing where the north is, it is easy to locate east and west.

In an open space around noon, we can also orient ourselves observing the position of the Sun. Spotting the Sun with your hand and moving your arm vertically downwards to the ground, you find the south cardinal point in the horizon. Now it's easy to locate all the other cardinal points.

Activity 2: A look at the polar star (10-15 min)

Part 1) Place the parallel globe as if you were at the North Pole. Put the observer with his/her horizon plane on the top.

Fig. 5 – The globe for an observer at the North Pole.

- Ask students which star they see above their head (zenith) at night. *(The polar star).* Ask them at what angle above the horizon they see this star. *(90º)*

Part 2) Now place the parallel globe as if you were at the equator, setting the stick and the cardboard horizon.

Fig. 6 – The globe for an observer at the equator.

- Ask students at which angle above the horizon they see the Polar Star. *(At their horizon plane, 0º).*

*You could give them some hint, like this: being the Earth in space extremely small compared to stellar distances to the Earth, the plane of the horizon at the *equator* and the plane that passes through *the poles* and the center of the Earth, which share the same direction, are practically the same).

Part 3) Place now the parallel globe for your current location.

- Ask students at which angle above their horizon they see the Polar Star. *(The angle is equal to the **latitude** of the location).*

- Challenge students to answer the previous question by taking a look at figure 7 and using simple geometry.

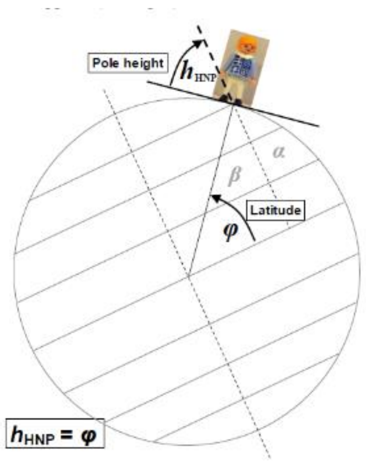
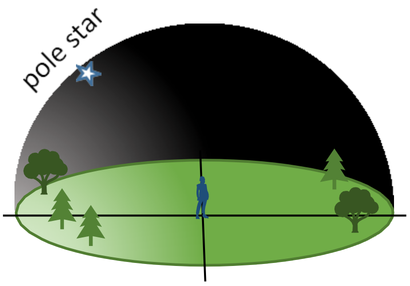


Fig. 7 - Observing the polar star from a certain location on Earth.

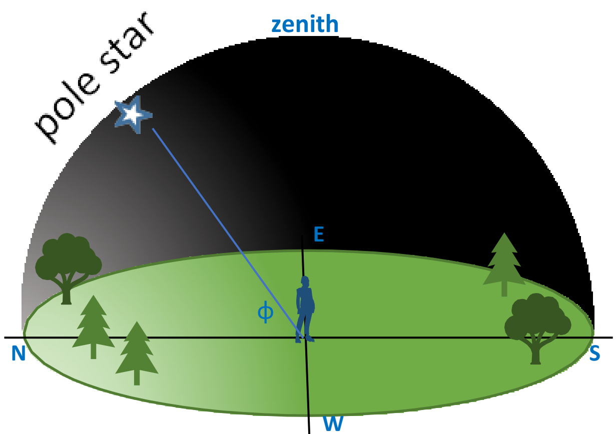
Exercise 1

- Give students the following exercise.



In the figure above, we see an observer watching the night sky. [Hint: directions N-S and E-W are traced with black lines]

- Indicate the zenith on the figure.
- Indicate on the horizon plane the four cardinal directions.
- Draw the connecting line between the observer and the pole star.
- Estimate the latitude of the observer.



To remember…

- The Earth is a **sphere** and there is no predetermined “up” and “down”. It has geographical north and south poles, but these are not everyone’s “up” and “down”. At any location on Earth, you are standing at the “top of the Earth”, with the rest of the planet underneath your feet. The north is not up, and the south is not down. In whatever direction you move from your standing point on Earth, you move “downwards”. No matter which location you walk to, in any direction, this location is always in a lower position than your initial one.

- The **inclination** of the earth's axis of 23.5° refers to the normal (perpendicular straight line) of the plane of the Earth's orbit, with respect to the Earth’s axis. The **horizon** is connected to the observer and the inclination of the Earth's axis on the horizon varies from one latitude to another, since it depends on where the observer is. But one thing is sure: The Earth's axis always points towards the **polar star**.

- The **cardinal points** are always to be found in the same way: The North towards the north pole of the Earth and the South towards the other pole. The projection of the direction of the polar star on the horizon plane of a place indicates the direction of the Earth's north pole and corresponds to the North geographical cardinal point. For each location in the northern hemisphere, the **height of the polar star** on the horizon is equal to the **latitude** of the location. The N-S direction, on the horizon plane, for each location, is always aligned with the meridian of the location.

Part 2 – Looking at the sky – Working with the bottle globe (60 min)

Background information

The celestial sphere is an imaginary sphere of arbitrarily large radius, concentric with the Earth. All objects in the observer's sky can be thought of as projections upon the inner surface of the celestial sphere, as if it were the inner side of a dome.

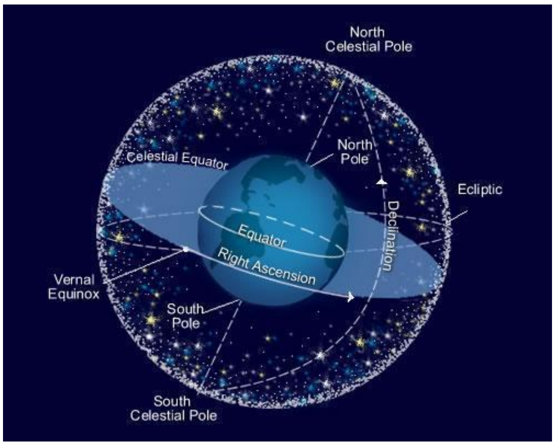


Fig. 8 – The celestial sphere (https://planetary-science.org/astronomy/the- celestial-globe/).

Working with a celestial sphere helps us to describe what we see from the Earth when looking up at the sky.

Bottle globe

For this part of the program we use the bottle globe, as a model of the celestial sphere, in which the Earth "transfers" distinctive features as shown below.
We also use the parallel globe to compare the different points of view.

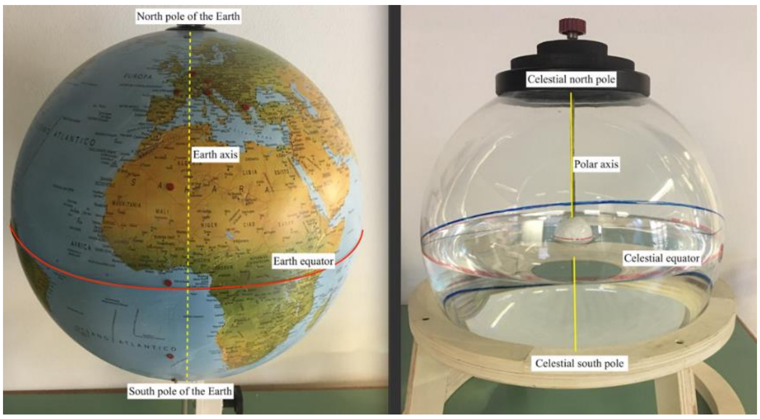


Fig 9: The bottle globe as a model of the celestial sphere

The elements that are representable on the bottle globe are the following:

- The Earth is in the center, representing yourself as the observer and your sky view.
- Above you there is the so-called “zenith”, below your feet there is the so-called “nadir”.
- The celestial equator is a circle shown in the bottle, concentric to the Earth’s equator (red on the small globe in the picture), and in the same plane.
- The plane of the horizon is represented by the water level.
- The Earth Axis and the polar axis, as well as the north and south celestial poles, are represented by the stick holding the small globe, the Earth.

*As the Earth is relatively so small that can be represented as a dot, the observer’s horizon plane (in the location of the North pole), the Earth’s equator, and the celestial equator can be considered in the same plane.

The bottle globe helps us to visualize what we see from the Earth. Using the bottle globe the students obtain a clearer representation of the apparent motions of the Sun and the stars over the horizon plane and in relation to the cardinal points.

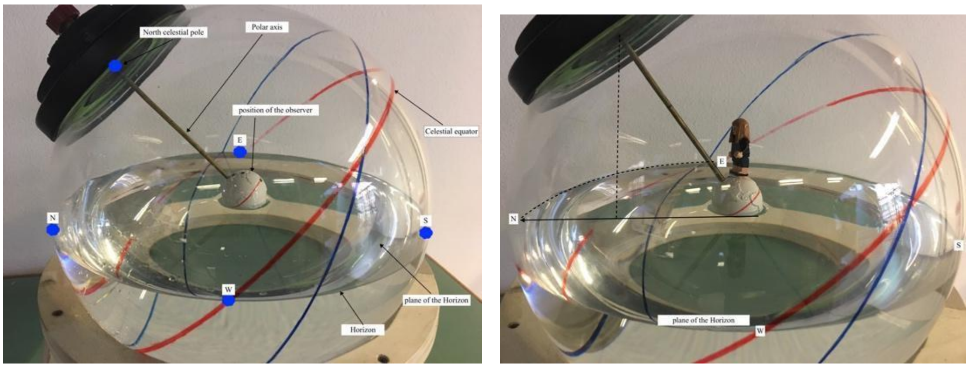


Fig 10: The bottle globe with labeled celestial lines and circles and the avatar as observer on Earth.

Materials

- The parallel globe

- The large 3d bottle globe

- The small 3d bottle globes (one every 2 or 3 students)

- Markers (not permanent)

- Stickers

- Rubbers (in a diameter that fits the small bottle bottles), or alternatively ribbon.

Activity 3: Look up! (20 min)

For this activity, the facilitator uses the large 3d models of the parallel globe and the bottle globe, while small bottle globes are given to students to work in pairs or groups of three.

- Place the large 3d models of the parallel globe and the bottle globe side by side.

- Explain that the bottle globe is a model that shows the Earth with the celestial sphere around it. It helps us to visualize what happens and what we can see in the sky, from different locations, during the day and the night.

A) Ask students to place their small bottle globes as shown in the picture below. Do the same using the parallel globe and the large bottle globe. Ask them to identify the celestial elements on their bottle globes.

- Ask students where they think the observer is standing. *(at the North pole).*

Fig. 11 – The parallel globe and the bottle globe with a north-pole view.

- Ask students where the polar star is to be found by the observer in this location on their bottle globes. *(Above their head, at the zenith, at 90º).*

B) Ask students to place their small bottle globes as shown in the picture below.
Do the same using the parallel globe and the large bottle globe. Now the observer's horizon plane and the celestial equator plane do not coincide, but they are perpendicular.

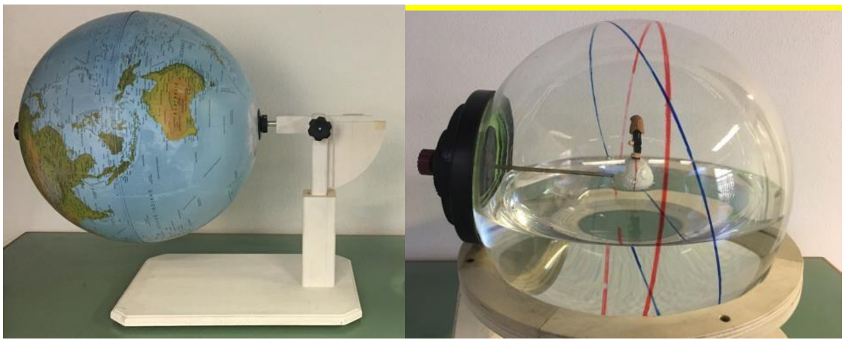


Fig. 12– The globes with an equatorial view.

- Ask students where they think the observer is standing. *(at Earth's equator).*

- Ask students, where on their globes the observer's zenith is and where the polar star is to be found, at what angle from the horizon. *(Above their head/ on their horizon, at 0°).*

C) Ask students to place their small bottle globes as shown in the picture below. Do the same using the parallel globe and the large bottle globe.

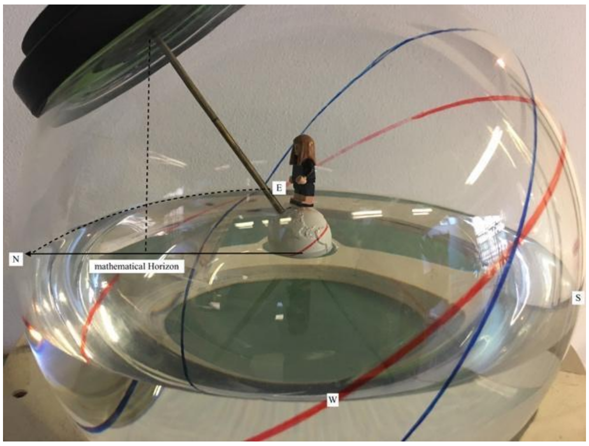


Fig. 13 – The globe for an observer in the northern hemisphere.

- Ask students where they think the observer is standing. *(They are standing at your current location).*

- Ask students to locate on their globes the observer's zenith and the polar star. At what angle from the horizon is the polar star located?

- Ask students to show on their globes the four cardinal points. *(The direction to the base of the perpendicular from the north celestial pole to the horizon plane specifies the north direction and defines the North cardinal point. The East and West points are created by the intersection of the celestial equator with the horizon*.

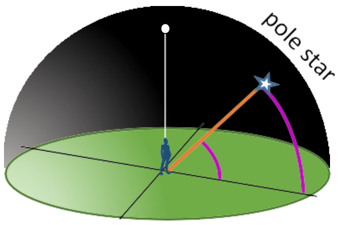
- Give the correct answers to the previous questions using the parallel globe and the large bottle side by side and setting them for each of the three different locations.

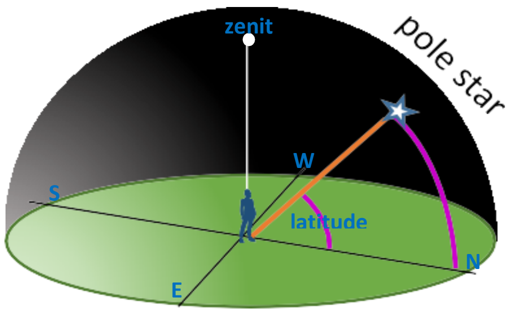
Exercise 2

- Give students the following exercise.

In the below picture you see an observer in the northern hemisphere watching the polar star.

- What does the white dot represent?
- Sketch the cardinal points.
- What does the purple arc represent?





Activity 4: The Earth's rotation and the starry sky (15 min)

- Place the large bottle globe with a north-pole view.

- Use stickers and mark 3 stars onto the large bottle globe: A star that is very close to the North Celestial Pole, NCP, a star that is at an angle almost 45° above the celestial equator and a star that is a little bit below the celestial equator. Ask students to do the same with their small bottle globes.

- Place both the parallel globe and the large bottle globe for your current location.

- Rotate the large bottle globe (celestial sphere) around the polar axis clockwise as seen from above the bottle's NCP. (Make sure that you do not change the tilt of the polar axis and no water is spilled out).

- Ask students to do the same with their small bottle globes.

- Ask students which motion of the Earth we are simulating this way. *(The Earth's rotation around its axis).*

- While rotating the globe, ask students to imagine that they are standing on the Earth, in the center of the bottle globe. Ask them to observe what happens to their horizon plane and what happens to the stars. *(The horizon retains its position. The position of the stars changes. They are running circles).*

- Ask them around which point in the sky they think the stars are rotating. In which direction? *(When seeing from the Earth the sky seems to rotate around the NCP counterclockwise -from east to west).*

Show the same motion (the rotation of the Earth around its axis) using the parallel globe. You have to rotate the parallel globe around its axis counterclockwise when looking at its North Pole. You will see the Earth rotating from West to East, which is the actual motion of the Earth.

To visualize what observers see observing the starry sky from different locations on Earth during the night (and during a full year), ask students to set their bottle globes for observers at latitudes 90°, 0° and 45 ° and write down their answers for each of the locations. You will summarize the correct answers in the end, using the large bottle globe.

A) Which stars can you see, if you are standing at the North pole? How do these stars seem to move? *(You can see half of the sky, meaning the stars* of the northern celestial hemisphere. *During 24 hours these stars are moving in circles parallel to the horizon. They never go below, so they are always visible. The stars of the southern celestial hemisphere, making parallel circles below the horizon, are always invisible).*

B) Which stars can you see, if you are standing on the equator? How do these stars seem to move? *(You can see all the stars of the celestial sphere, that are above the horizon. Stars both from the north and south celestial hemisphere are visible. During 24 hours, the stars run in circles perpendicular to the local horizon, rising east and setting west. In a full year's time, all the stars can be observed, because every star, following its trail which is perpendicular to the horizon, will pass at some point above the horizon).*

C) Which stars can you see, if you are standing at your current location? How do these stars seem to move? *(Not all the stars of the celestial sphere are visible. You can see* *part of the sky, depending on your latitude. For 24 hours the stars run circles that intersect the local horizon, rising east and setting west. In a full year's time there are stars that are visible every night (always above the horizon – circumpolar) and there are stars that are never visible (always below the horizon- non visible . All the other stars, rising east and setting west, are visible at some part of the year – seasonal stars.*

To remember…

Stars have fixed positions on the celestial sphere. However, looking up at the sky, we see an apparent motion of the stars during the night. This. This apparent motion, called **star trail,** for an observer in the northern hemisphere proceeds from the eastern region of the sky over south to the western region of the sky (counterclockwise looking at the NCP). The star trails are different for different locations on Earth.

The apparent motion of stars is happening due to the Earth's rotation around its axis. When viewed from "above", meaning for an observer placed on the NCP outside the celestial sphere, the Earth rotates around its axis counterclockwise. To this "exterior" observer this motion of the Earth produces the effect that, standing still, she/he sees the sky with the celestial objects rotating clockwise. The effect is quite the opposite for the observer on Earth, who as observing the night sky from "below" sees the stars moving counterclockwise, rising east and setting west.

Activity 5: The daily path of the Sun (15 min)

We can also use the bottle globe to observe the Sun's daily motion.

- Place the large bottle globe for your current location. Ask students to do the same with their small bottle globes.

- Mark the sun at an arbitrary point of the Ecliptic of your bottle globe to show its position on the celestial sphere. Ask students to do the same on their small bottle globes.

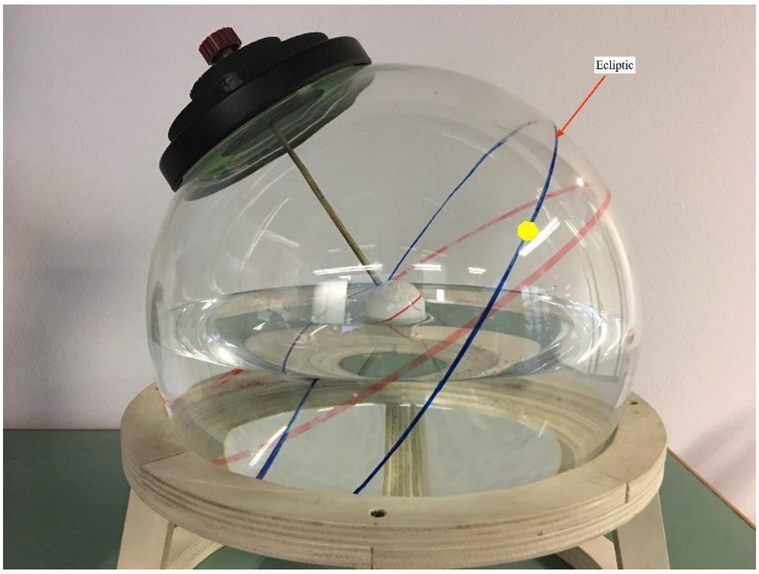


Fig. 14 - The bottle globe with the Sun yellow-marked on the Ecliptic and the celestial equator red-marked.

- Ask students to simulate the Earth's rotation around its axis and to describe the Sun path (the Sun's apparent motion). Ask them whether they can distinguish the night from the day. *(The Sun following its path seems to orbit the Earth. During this path, when the Sun is above the horizon -water level- is visible and it is day in this location. When the Sun is below the horizon it is invisible and it is night in this location).*

With the following questions try to make students connect the Sun's motion on the sky with the cardinal points:

- Close to which compass direction does the yellow-marked sun rise above the horizon? *(East)*
- Close to which compass direction is the sun inclined the most (culmination point) above the horizon? *(South)*
- Close to which compass direction does the Sun sink below the horizon? *(West)*

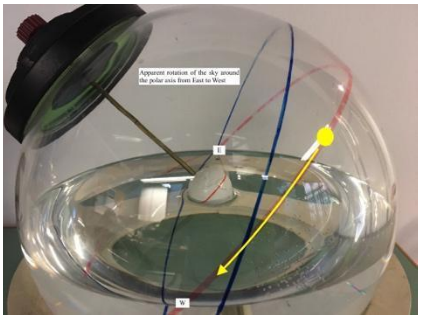


Fig. 15 – the apparent motion of the Sun around the polar axis from east to west.

* For this activity we choose to mark the Sun on the celestial equator. This is happening only at the equinoxes, two times in a year. Only then the Sun’s path is exactly on the celestial equator, rising exactly from the East and setting exactly at the West -the intersection points of the ecliptic and the celestial equator and day and night have the same duration

- Change the inclination of the polar axis, simulating an observer in some other location on Earth. Ask students what has changed about the Sun's motion, its orbit, its visibility. *(The Sun has a different path. The height of the Sun in culmination is different. The day and night have the same duration).*

To remember…

We see the Sun in the sky moving from east to west. This is an apparent motion due to Earth’s rotation. The Sun seems to describe circles on the celestial sphere, which are parallel to the celestial equator. The path that the Sun follows in the sky is called the Sun's path and this path is different for different locations (latitudes) on Earth.

However, for any observer in the northern hemisphere, the Sun rises close to the east direction, reaches its highest point in the direction of the south and sets close to the west direction, creating the day and the night. The duration of day and night also differs depending on the latitude.

Activity 6: The Earth's revolution and the seasons (10 min)

The bottle globe can be used to simulate the apparent yearly motion of the sun and observe its daily path at different seasons.

On the bottle globe the blue line is called the "ecliptic" circle and represents the Sun's path during the year, as seen from the Earth. The ecliptic circle is tilted (about 24°) with respect to the celestial equator due to the Earth's axis tilt.
The ecliptic circle intersects the celestial equator in two points. These points represent the days when spring and fall begin and are called equinoxes. The beginning of summer is when the Sun is at its highest point above the celestial equator and the beginning of winter is when the Sun is at its lowest point below the celestial equator. These days are called summer solstice and winter solstice.

- Ask students to observe the bottle globe and see how many times a year the path of the Sun (ecliptic) cuts the celestial equator. (Twice a year. They are the points of intersection between the ecliptic and the celestial equator). Ask them to show these points on the bottle. Ask them what these points represent. (The equinoxes).

- Ask students how many times a year the Sun is at its highest point above the celestial equator and at its lowest point below the celestial equator? Ask them to show on the bottle these points and to tell what these points represent (Once per year is at its highest point and once per year is at its lowest. They represent the solstices).

Turning back from the annual Earth's revolution around the Sun to the daily rotational motion around its axis, we are using the bottle globe to visualize the Sun's position and its daily path at different times a year, for a specific location.

- Having the large bottle globe placed for your current location, follow the next steps.

A) *Place the bottle globe for an observer on the northern hemisphere as shown in the below figure (summer solstice). Ask students to do the same with their small globes.*

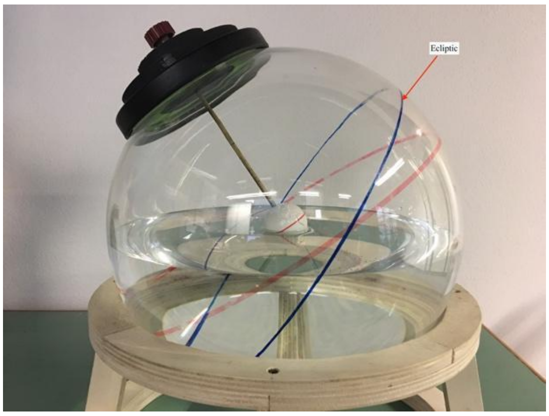


Fig. 16 - The bottle globe with the Sun culminating in the summer solstice for an observer on the northern hemisphere

- Ask students to use the rubber to show the daily path of the Sun for this specific day.

*Give them the hint to use the sunrise to help them in this task. *(The sunrise happens when the Sun elevates above the horizon at the exact point where lies the ecliptic line. Having this* *point as a reference the rubber must be placed in a parallel circle to the celestial equator).*

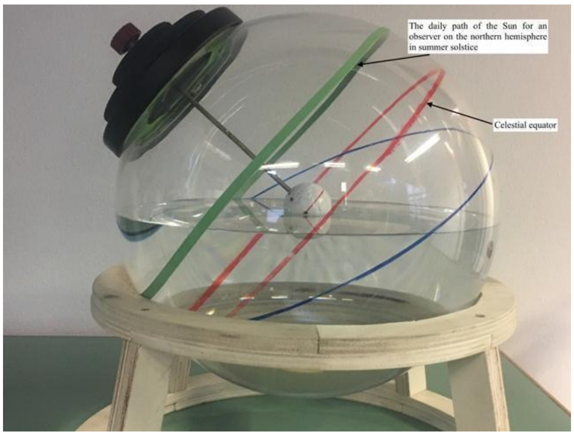


Fig. 17 - The daily path of the Sun for an observer on the northern hemisphere in summer solstice

- Ask them the following questions:

- What is the duration of the day compared to the duration of the night?

A) longer B) equal C) shorter

- In which time of the year does the Sun follow this daily path?

A) spring B) summer C) autumn D) winter

B) *Without changing the tilt of the axis, place the bottle globe for the spring/autumn equinox (the intersection point of the celestial equator and the ecliptic meets the horizon line). Ask students to do the same with their globes and ask them again the questions above. (Day and night have the same length. It is the beginning of spring/autumn).*

C) *Ask students to use a rubber band and place it on the globe to show the Sun's daily path at the time of the year when the duration of the night is the longest (for the same observer).*

- Ask them what time of the year the Sun has this daily path? (It is the beginning of the winter)

The points where the ecliptic meets the celestial equator represent the days when spring and autumn begin. At the equinox's points, the time periods when the Sun is above the horizon and below it are equal. Day and night have the same duration.

The biggest culmination height is seen at the summer solstice, at the beginning of the summer. The Sun has the longest path above the horizon on this day, which is moreover the longest day of the year. The smallest culmination height is seen in the winter solstices, at the beginning of winter. The Sun has the shortest path above the horizon on this day, which corresponds to the longest night of the year.

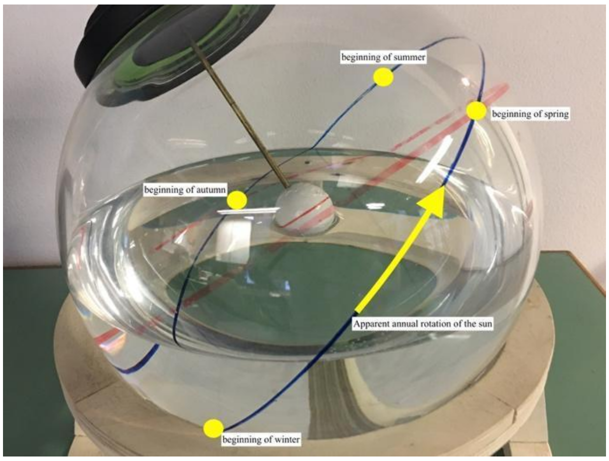


Fig. 18: The apparent annual rotation of the Sun

To remember…

Observing the Earth from outside our planet we see it orbiting the Sun with its revolution motion. The almost circular orbit of the Earth lies in a plane called the **Ecliptic plane**. This motion of the Earth results in the apparent motion of the Sun along the ecliptic line, while observing the sky from Earth. Earth's axis is tilted approximately 23,5° with respect to the ecliptic plane, and this inclination doesn't change during the revolution. For this reason, on the Earth we experience different **seasons**, with different Sun culmination points in the sky.

In the days in which spring and autumn begin, the Sun is found in the intersection points between the ecliptic and the celestial equator. On these days, called equinoxes, the time periods that the Sun is above or below the horizon are equal. Day and night have the same duration.

The biggest culmination height is seen at the **summer solstice**, when the **summer** begins. On this day, the Sun has the longest path above the horizon, it is the longest day of the year. The smallest culmination height is seen in the **winter solstice**, when **winter** begins. The Sun has the shortest path above the horizon this day, which corresponds to the longest night of the year.

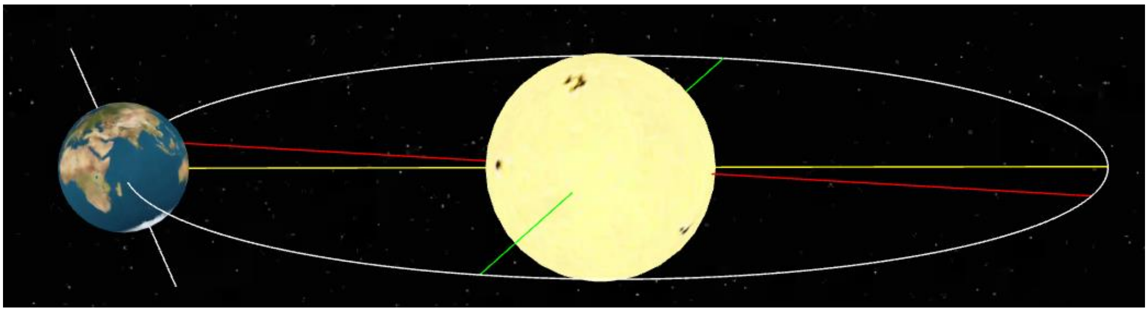


Fig. 19 – The Earth position in January, Winter for the boreal hemisphere.

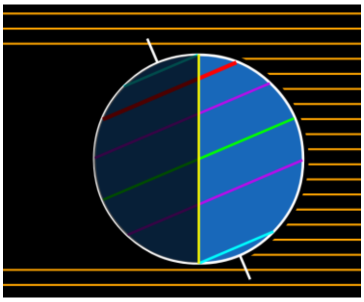


Fig. 20 – The sunbeams inclination in the same date as above,
for a latitude of 45° (vivid red parallel)

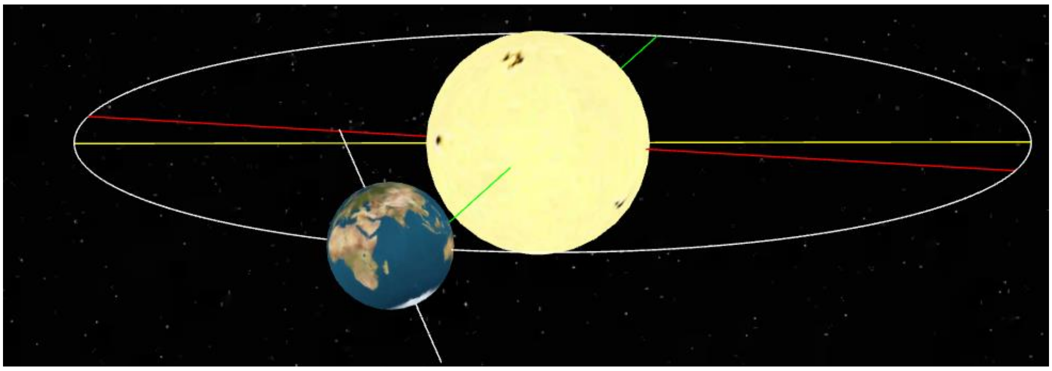


Fig. 21 – The Earth position in March, close to the spring equinox.

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TASTE

Teaching Astronomy at Educational Level

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