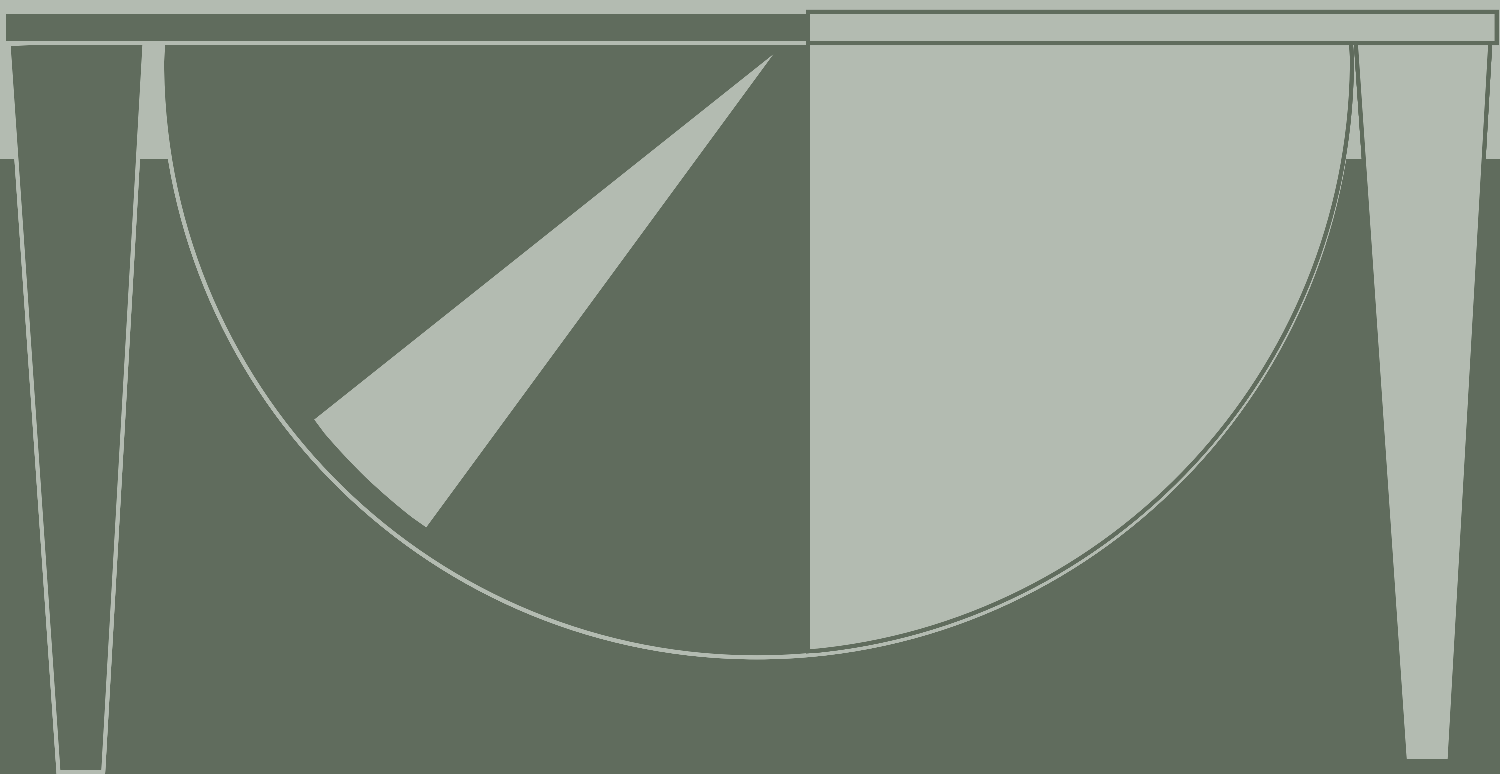
<For Teacher>

Exploring the Principles of Angbuilgu



Exploring the Principles of Angbuilgu

Integrating Curriculum Unit – Exploration of the Universe : Exploring the Principles of the Sundial

Learning Objectives

1. **I can explain the functions and principles of each structure in Angbuilgu.**
2. **I can create an Angbuilgu model that corresponds to the latitude and measure time.**
3. **I understand and can discuss the concepts of the celestial sphere, time, and calendar.**

I. Postscript

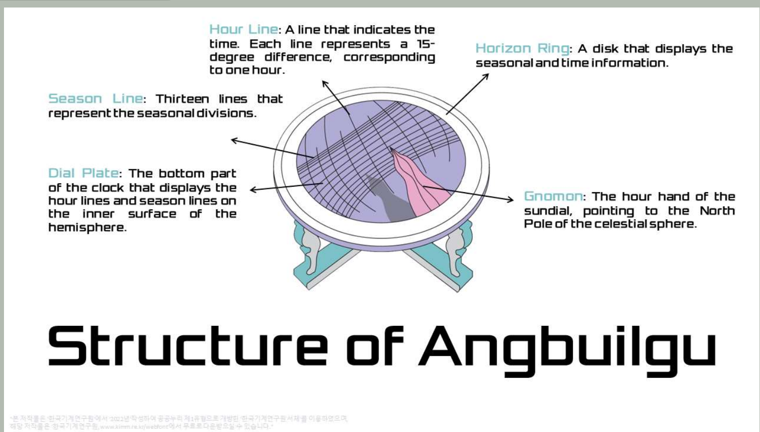
- How did people measure time in the past when there were no mechanical clocks?
- How does Angbuilgu which is a sundial developed during the Joseon Dynasty function?
- What are the characteristics of Angbuilgu?
- If you Wake up in the morning and are given a stick and a sundial, would you be able to estimate the time?

II. Overview

Throughout history, people have created and used various timekeeping devices such as water clocks and hourglasses to measure time. However, these devices had the drawback of not representing a consistent flow of time. In the eyes of ancient people, the most consistent motion they observed was that of celestial bodies, particularly the sun, which displayed regular movements. Therefore, by observing the motion of celestial bodies, especially the sun, people sought to measure time accurately. To make time measurement accessible even to those who found it difficult to determine time based on celestial motion alone, a hemisphere-shaped sundial called "Angbuilgu" was created.

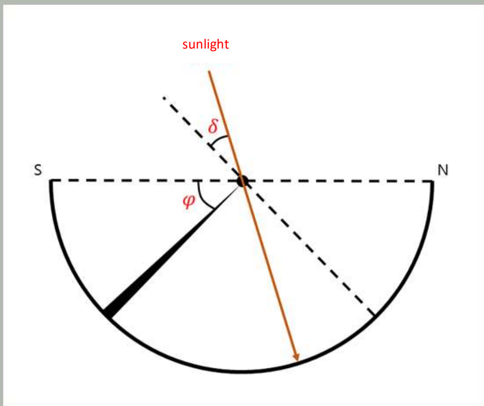
Angbuilgu (앙부일구) was developed in the 16th year of King Sejong's reign (1434) by Jang Yeong-sil, Yi Cheon, Kim Jo, and others. Its appearance resembles a concave clock face, shaped like a cauldron, symbolizing the cauldron reaching towards the sky. Angbuilgu exhibits the following characteristics.

Detailed Examination



The base of the sundial, which serves as the bottom part of the clock, has a rounded shape and is divided by a total of 7 vertical lines and 13 horizontal lines. The 7 vertical lines represent the hour lines and indicate the time based on the position of the shadow throughout the day. Each hour difference is marked with a 15-degree variance from the center of the sphere. The seasonal lines represent the 24 solar terms, with the topmost line indicating the winter solstice (dongji) and the bottommost line representing the summer solstice (haji). On top of the sundial's base, there is a horizontal plate extended from the seasonal lines, which displays the solar terms corresponding to each seasonal line and the latitudes where the sundial can be used.
The gnomon, or shadow-casting object, plays a role in creating a shadow on the surface of the base. By reading the surrounding seasonal and hour lines based on the position of the shadow's end caused by the gnomon blocking the sunlight, one can determine both the solar term (date) and the time.

Detailed Examination



The gnomon of the sundial is designed to point towards the celestial pole, which is the north celestial pole. Therefore, when extended, the gnomon forms an angle with the horizontal plane that is equal to the latitude (φ). When sunlight falls onto the sundial, it enters at an angle δ with respect to the plane perpendicular to the gnomon. As a result, the seasonal lines are drawn on the plane perpendicular to the gnomon, inclined by the daily declination value of the sun for each of the 24 solar terms.

III. Suplies

- 3D Printer
- Compass
- Level

IV. Process

(1)Printing the Sundial
Generate an Angbuilgu model that corresponds to the desired latitude. Enter the desired location on a website and create the model, printing the Angbuilgu to a size of about 18cm.

(2)Installation of the Sundial
Place the Angbuilgu on a flat surface without any slope. If the ground is not level, use a desk or tripod to adjust the horizontal position of the Angbuilgu. Conduct the experiment in a spacious area without any buildings obstructing the sunlight.

(3)Alignment with True North
Use a compass to determine the direction of the magnetic North Pole. Align the Angbuilgu towards true north, correcting the declination by matching the long line extending to the horizon (not the line marked with "N") with the north indicated by the compass. Ensure that the gnomon points towards the celestial North Pole.

(4)Recording the Readings
Observe the position of the shadow's end on the sundial's surface, which is created by the gnomon blocking the sunlight, and determine the time accordingly. Record the time indicated by the sundial as well as the time obtained from a satellite clock (e.g., smartphone clock). Repeat the measurements approximately three times at regular intervals.

CHECK!

•Ensure that the Angbuilgu is accurately installed by using a level to achieve proper horizontal alignment.
•Install the Angbuilgu gnomon in a way that it points towards the celestial North Pole.
•Securely fix the Angbuilgu during the measurements to prevent any changes in its designated position.
•Not following the above precautions may result in significant errors in the readings.

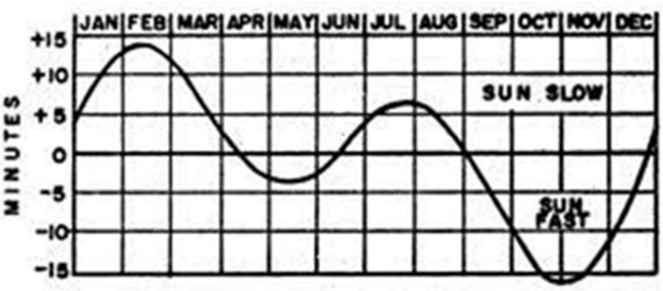
(1)Let's record the measurement values and also note the corresponding solar terms and Time

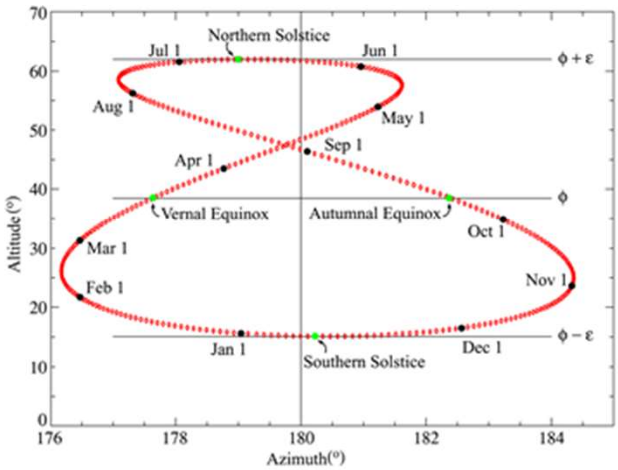
latitude		longitude		Declination	
YYYY		MM		DD	

	1	2	3
The time observed using the Angbuilgu.			
The time confirmed using the satellite clock.			

(2) When recording the measurement values, did the solar terms appear consistently? If not, let's analyze the reasons.
If the solar terms appeared consistently, meaning that the shadow's end moved parallel to the seasonal lines, it indicates that the installation was done very accurately. If the solar terms did not appear consistent and errors occurred, the reasons could be attributed to errors during the installation process. If the horizontal alignment was not precise or if the gnomon did not point towards the celestial North Pole (incorrect direction), significant errors in time measurement could occur. While the Angbuilgu sundial was originally fixed at specific locations, minimizing directional issues, it is crucial to ensure accuracy during the initial installation process and maintain that state during the experiment.

(3) What could be the reasons for the discrepancy between the time observed using the Angbuilgu sundial and the time confirmed using the satellite clock?
One significant reason is the equation of time. The equation of time refers to the difference between the time read from a sundial (solar time) and the time read from a mechanical clock (mean solar time). During the 17th and 18th centuries when the Angbuilgu sundial was commonly used in Joseon, time was standardized based on sundials, so there was no issue with using it. However, in modern times, mean solar time is used, which results in a discrepancy between the two. This difference arises due to the tilt of the Earth's axis and the ellipticity of its orbit, causing the apparent motion of the sun projected onto the celestial equator to be non-uniform. The commonly known horizontal component of analemma becomes the equation of time.





The graph (left) displaying the equation of time values by month and the analemma curve (right). The horizontal component of the analemma curve becomes the equation of time.

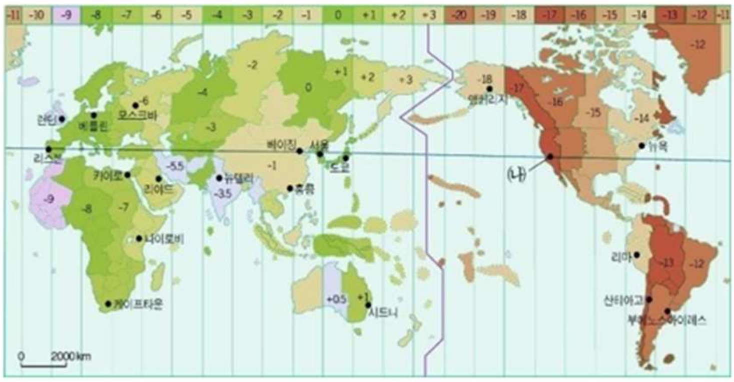
(4) Let's compare the time observed using the Angbuilgu sundial, corrected for the equation of time based on the annual publication of the Korean Astronomical Observatory, with the time confirmed using the satellite clock. (As of the production date in 2023, refer to the '2023 Astronomical Ephemeris (pg. 96–101)' available at https://www.kasi.re.kr/kor/publication/post/publication?clsf_cd=pub005 for the equation of time table.)

The equation of time can be calculated as (solar time – mean solar time). Therefore, by subtracting the equation of time from the time observed using the Angbuilgu sundial, we can obtain the mean solar time value.

(5) Is the time difference still evident as observed in (4)? If there is a difference, let's consider the reasons behind it, brainstorm potential methods of adjustment, and discuss them.

Yes, there is still a time difference. The reason for this is that South Korea uses local mean time based on the meridian of Tokyo. Local mean time is established by aligning the time of a specific location with the 15-degree increments of longitude from the Prime Meridian at Greenwich. The designated time at each 15-degree interval is known as the standard time. Regions that fall within the same meridian as the standard time are referred to as standard time zones. Seoul, for instance, has a longitude of 126.98 degrees, which does not evenly divide by 15 degrees. According to Korean law, a meridian of 135 degrees is adopted as the standard meridian for time calculation. Therefore, additional calculations need to be considered, taking into account the local mean time. As each 15-degree difference corresponds to a one-hour time difference, there is a four-minute difference per degree. For example, if we check the time at a longitude of 127 degrees, which differs by eight degrees from the standard meridian, we need to subtract 32 minutes from the mean solar time to obtain the accurate time according to satellite clocks.

Korean Standard time (GMT+9)

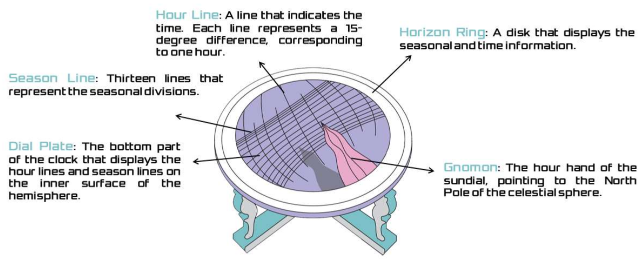


An illustration depicting Korean Standard Time (left) and the world standard time with regional time zones (right).

VI. Summary

Overview

- Angbuilgu: A sundial in the shape of a hemisphere that can estimate time based on the movement of the Sun.
- Hour Line: A line that indicates the time. Each line represents a 15-degree difference, corresponding to one hour.
- Season Line: Thirteen lines that represent the seasonal divisions.
- Dial Plate: The bottom part of the clock that displays the hour lines and season lines on the inner surface of the hemisphere.
- Gnomon: The hour hand of the sundial, pointing to the North Pole of the celestial sphere.
- Horizon Ring: A disk that displays the seasonal and time information.
- Tilt of the Gnomon: The tilt of the gnomon on the dial plate, which changes according to the Sun's declination value based on the date.



Structure of Angbuilgu

Materials:
•3D printer
•Compass
•Spirit level Procedure:
(1) Print the sundial.
(2) Install the sundial.
(3) Align it with true north.
(4) Record the data.
Results and Discussion: Record the measurement values.
Record the accurate seasonal values.
Relate (3,4) to the equation of time and the analemma curve for better understanding.
(5)Understand the concept of standard time.