INTRODUCTION

Prerequisite Knowledge

- Basic familiarity with the Earth-Sun orbital system
- Basic understanding of how the tilt of Earth's rotational axis affects the number of daylight hours and intensity of light experienced by Northern and Southern Hemispheres for different times of year

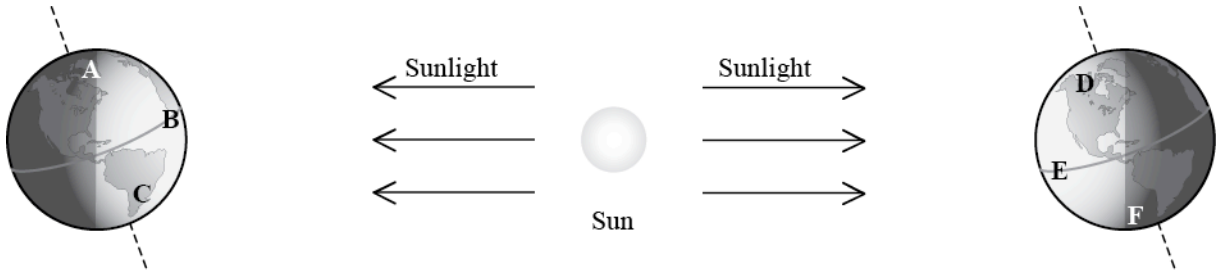
Goals

- Be able to reason about tilt causing seasons because the tilt changes the number of daylight hours and intensity of the sunlight during different times of the year as Earth orbits the Sun
- Be able to reason about situations in which a location on a hypothetical planet might experience a summer or winter day
- Practice with analytical reasoning skills

Pre-activity Question

1) Imagine that Earth's orbit were changed to be a perfect circle around the Sun so that the distance to the Sun never changed. How would this affect the seasons?
   b) We would no longer experience a difference between the seasons.
   c) **We would continue to experience seasons in essentially the same way we do now.**
   d) We would still experience seasons, but the difference would be *much more* noticeable.
   e) We would still experience seasons, but the difference would be *much less* noticeable.

2) Which lettered position (A-E), in the image below, best represents the location on Earth that is experiencing winter in the Northern Hemisphere? **[A]**



Note: this drawing is not to scale. In fact you could fit more than 100 Suns between the Sun and Earth.

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1) **[No]**

2) **[No]** Earth is closest to the Sun in December (winter for the Northern Hemisphere), and Earth is farthest from the Sun in June (summer for the Northern Hemisphere.

3) **[No]**

4) **[No; winter]**

Questions 1-4 elicit students' incorrect initial ideas about seasons, which typically involve reasoning that the differences in Earth's temperature are due to the changing distance between Earth and the Sun.

5) **[Student 2 is correct]** Student 1 incorrectly thinks that the distance between Earth and the Sun causes seasons even though Question 1 shows that Earth is actually closest to the Sun in winter and furthest from the Sun in summer (for locations in the Northern Hemisphere). Student 2 correctly states that if the cause of the seasons were due to distance than the Northern and Southern Hemispheres would not experience opposite seasons at the same time.

6) **[No]** The change in distance between Earth and the Sun changes by a few million kilometers throughout the year, as is shown in the table. And the difference between the locations on Earth at the same latitude are only different in distance to the Sun by a few thousand kilometers due to the tilt of Earth's axis. If millions of kilometers isn't enough change in distance to cause seasons, then thousands of kilometers can't be either.

Some students will still want to think that the distance between Earth and the Sun causes the seasons. These students may decide that it is possible that having one hemisphere closer the Sun due to Earth's tilt can cause the seasons. This is a way of incorporating what they believe is the root cause for the seasons (seasons due to distance), with the idea they have been told that is responsible (Earth's tilt). The Student Debate in Question 5 will help to resolve this.

7) **[Student 2]** Student 1 still states that the distance between Earth and the Sun causes seasons even though, as Student 2 correctly states, the difference in distance caused by the tilt of Earth's axis is much smaller than the difference in orbital distance between Earth and the Sun throughout the year.

8) **[Spotlight A's area]**

9) **[Spotlight A's area]**

10) **[Spotlight A's area]**

11) **[Spotlight A's area]**

12) **[Spotlight B's position]**

13) **[D]** Locations above the equator are in the Northern Hemisphere. These locations would experience summer when that hemisphere is tilted toward Earth. Only Position D is above the equator (in the Northern Hemisphere) while the hemisphere is tilted toward the Sun.

14) **[F]** Locations below the equator are in the Southern Hemisphere. These locations would experience winter when that hemisphere is tilted away from Earth. Only Position F is below the equator (in the Southern Hemisphere) while the hemisphere is tilted away from the Sun.

15) **[Summer; Some number greater than 12 hours]**

Some students may get stuck here because they don't know the exact number of hours of daylight there are at their location in summer. When working with members of a group it can be helpful to tell them the exact hours of daylight isn't important, but ask if it is less than, equal to, or more than twelve hours?

16) **[Summer]**

17) **[The same]** There are more hours of daylight, and the Sun is high in the sky at noon, at the same time of year that the average temperature is high. This all happens during the season known as summer. We can then say that more daylight hours, with the Sun's light being more intense (due to the Sun being high in the sky), causes the average temperature to be high.

18) **[Very little]** The number of hours of sunlight, and the height of the Sun in the sky at noon, would change very little over the course of the year for locations on the equator because the amount that these locations are tilted toward or away from the Sun changes very little throughout the year.

19) **[Yes; No]** If the number of daylight hours did not change throughout the year, but Earth was still tilted at 23.5°, there would still be seasons, but the difference between the seasons (and the temperatures experienced) would not be as great. The tilt of Earth's axis causes the intensity of the Sun's light on Earth to change throughout the year, and it causes the change in the number of hours Earth receives this light. By removing one of the factors—the number of daylight hours—the effect would be reduced. However, the intensity of the light Earth receives from the Sun would still be changing throughout the year, so we would still have seasons.

It's important to note that the physical situation described in this problem is not possible. Some students will bring this issue to your attention and ask for clarification. Rather than debate whether the scenario presented is possible we suggest that you acknowledge their concern but focus their attention on answering the question based on the scenario presented.

20) **[Arctic Circle]** If Earth were tilted 90°, the Arctic Circle would be warmer in the summer because it would be tilted directly at the Sun. This would cause the light to be directly overhead for 24 hours a day. While in Florida, even though the Sun would still be up for 24 hours, it would be low on the horizon because Florida is much closer to the equator. This would cause Florida to be much cooler than the Arctic Circle during summer.

21) **[The Northern and Southern Hemispheres do not experience the same season at the same time. Also, Earth is closest to the Sun when the Northern Hemisphere is experiencing winter. So, the varying distance between Earth and the Sun cannot account for the seasons.]**

Students may have other correct answers here, but the most important answer they should NOT have is something along the lines of "The Northern and Southern Hemispheres do not experience the same seasons at the same time because the Earth's axis is tilted." This, alone, is an insufficient answer to assess whether or not students are still using a "closer means hotter" distance model, which means they could still believe the seasons are caused by the tilt of Earth's axis because this causes one hemisphere to be closer to the Sun than the other.

22) **[The two things that are most directly responsible for the cause of the seasons on Earth are the change in the number of daylight hours and the change in the intensity of this daylight.]**

Many students will simply want to site the tilt of Earth here. It's important to have them articulate what the tilt physically causes to occur that is responsible for changing the surface temperature of Earth and thus causing the different seasons.