An inquiry-based laboratory lesson to construct an understanding of Earth’s seasons

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Abstract

This paper shares an innovative approach to teaching prospective elementary teachers about seasons within the context of a college science content course. An inquiry-based lesson in an undergraduate physical science course was designed to help non-majors address a common misconception of the cause of the seasons by requiring them to construct an explanation based on astronomical data. The students’ misconception of the seasons caused by the distance to the Sun is mathematically discounted, and responses to the pre-post test questions show significant learning. Over 90% of the students received full credit for their explanations of the cause of the seasons on the post-test.
An inquiry-based laboratory to construct an understanding of Earth’s seasons

Teachers are expected to teach science using an inquiry approach (National Research Council [NRC], 1996), yet novice and preservice teachers tend to exhibit behaviors in the classroom that can only be modeled on their past experiences as students (Lortie, 1975; Richardson, 1996; Weinstein, 1989). In addition, research indicates that many preservice elementary teachers have limited subject matter knowledge, often holding the same misconceptions as the students that they will teach (Anderson & Mitchener, 1994). It has been demonstrated that preservice teachers participating in inquiry-based instruction were more likely to develop meaningful scientific conceptions compared with preservice teachers having other types of instruction (Trundle, Atwood, & Christopher, 2002).

If teachers tend to teach as they were taught, their experiences as learners during their twelve to sixteen years as students have provided many examples of teaching and learning that are not easily displaced. Alberts (in NRC, 2000) describes a type of science teaching where “teachers provide their students with sets of science facts and with technical words to describe those facts” (p. xii). Alberts goes on to describe this as training for a quiz show as opposed to learning why the phenomena occurs. Students will learn the facts to answer the appropriate exam questions and, with time, forget the material. Once the new material is forgotten, the students will go back to their original explanations.

Students and adults very often misunderstand the reasons why we experience seasons in the mid-latitudes (Harvard-Smithsonian Center for Astrophysics [HSCA], 1997). A very common misconception is that during the summer months, the Earth is closer to the Sun and warmer, and during winter, the Earth is farther away. The constructivist theory of learning (von Glaserfeld, 1989; Driver, Asoko, Leach, Mortimer, & Scott, 1994) is based upon students
constructing and reconstructing basic concepts based on their own experiences and behaviors. When students learn that being close to a fire makes one warmer while being further away makes one colder, it is a easy step to use this knowledge to explain the seasons. The hot summer sun feels very near compared to the “distant sun” of the winter. Once students have this understanding, there is no reason for them to look for another explanation.

Studies have investigated another astronomical concept, the way students understand the reasons for the phases of the moon. A study by Targan (1988, as cited in Trundle, et al. 2002) of college non-science majors gave pre- and post-test open-ended questions with written responses about the reasons for the phases of the moon. Targan found that the percentage of 61 participants having a scientific conception rose from 1.6 percent (one respondent) on the pre-test to 18 percent (11 respondents) on the post test. Callison and Wright (1993) found that of 76 elementary pre-service teachers, 6.6 percent had a scientifically accepted conception of moon phases before instruction with models in a science methods class and only 22.4 percent had a scientifically accepted conception of moon phases after instruction. Trundle, et al (2002) lists other studies where a large percentage of students do not have scientifically accepted conceptions of moon phases either before or after instruction (Table 1, p. 635).

Theoretical Framework

Posner, Strike, Hewson, and Gertzog (1982) believe that for a conceptual change to take place a student must discover errors in their previous thinking. Hewson and Hewson (1988) contend that a student must be confronted by a situation that their current understanding cannot explain before the student would be ready to adopt a new explanation. The student must become dissatisfied with his or her own explanation of a scientific concept before adopting a new one. Hewson proposed that students must not only become dissatisfied with their own current
explanation of a scientific concept, but that the new explanation must be intelligible, plausible and fruitful. In other words, students must understand the concept, find it reasonable, and be able to apply the new understanding with success.

The National Research Council (2000) defines classroom inquiry by describing five essential features. Students ask scientifically oriented questions, analyze evidence that allows them to formulate explanations, connect explanations to scientific knowledge, then communicate and justify their new explanations. Students have the opportunity to consider alternative explanations, including their misconceptions and use the data (evidence) to discount them. Since the inquiry has a larger amount of learner self-direction and a smaller amount of direction from the teacher or material, the students may reconstruct their basic concept based upon the learning experience.

Relation of this work to other efforts

Science teachers who work with an inquiry curriculum have a significant positive effect on student performance (Shymansky, Kyle, & Alport, 1983). Teachers are expected to teach in an inquiry approach, yet teachers need to exhibit behaviors that can only be modeled on past experiences when they were students (Lazarowitz & Tamir, 1994). This laboratory lesson has been explicitly designed to implement the five essential features of inquiry as well as providing opportunities for the students to replace any alternate conceptions they may hold. It involves a commonly experienced and commonly misunderstood science phenomenon (HSCA, 1997). The students are given data from an astronomical almanac and asked to manipulate the data to formulate explanations. When they consider the effect of a common misconception, students see that it has little influence compared with other factors.

Lawson, Abraham, and Renner (1989) argue that the use of the learning cycle in a laboratory exercise allows students to reveal their own misconceptions, be able to test them, and
develop more correct conceptions and thinking patterns. In the field of biology, Nazario, Burrowes, and Rodriguez (2002) identified common undergraduate misconceptions that persisted throughout the semester. They felt concrete examples would help invalidate the misconceptions and suggest that professors in other disciplines “may also consider bringing pertinent laboratory activities to the classroom” to accomplish this goal.

Other work similar to this lesson includes Larsen (2000) describing how students used the learning cycle to personally discover fossil evidence leading to conclusions of evolution that were more convincing to the student than if the student learned about the conclusions of others. Barnett, Barab, and Hay (2001) teach a semester class, Virtual Solar System, where students build a complex computer model of the solar system with project-based learning that emphasizes long term, student-centered inquiry. Aubrecht (2000) suggests looking at seasons qualitatively by modeling a beach ball illuminated by a strong lamp, showing a longer time of daylight when the tilt of the ball points towards the lamp and a shorter time when pointed away.

The purpose of this study was to examine the effects of an inquiry-based lesson intervention on understandings of seasons held by college level, general education, physical science students. This paper describes the 5-E lesson and the embedded interventions used with students and the learning gains that resulted.

Context and Methods

This study took place within the context of a general education physical science course at a medium sized, rural, four-year, Midwestern university. About two-thirds of the 151 students enrolled in the five sections of the course were elementary education majors, predominantly women, and predominantly juniors with the other third being non-science majors fulfilling general education requirements. The reason for seasons is common curricula for the elementary grades, and is Standard 3.4 D of the Pennsylvania Academic Standards for Science and
Technology (PDE, 2002). Thus, the goal was for pre-service teachers to both learn the content through inquiry and experience inquiry-based teaching methodologies.

Trundle, et al (2002) listed various studies where students continued to hold incorrect explanations for the phases of the moon at the end of their coursework. The Private Universe (HSCA, 1997) video shows that only two of 25 Harvard graduates, alumni and professors correctly explained the reason for seasons. In previous semesters, a majority of students in this course held incorrect explanations for the seasons at the beginning of the semester (Authors, 2002).

Authors (2002) designed a lesson (Appendix II) following the 5E lesson planning model (Trowbridge, Bybee, & Powell, 2000) (Appendix I) that incorporates analysis of concrete evidence of the Earth’s tilt being the main cause for the seasons. The 5E model provides instructors guidance and planning framework that incorporates all five of the essential elements of scientific inquiry (NRC, 2000), is based on constructivist learning model (Driver, et al. 1994), and conceptual change teaching strategies (Hewson, Beeth, & Thorley, 1998; Posner, et al. 1982). A lesson sequence that is planned following this model will provide an opportunity for students to confront their ideas, judge their usefulness, discard the misconception, and reconstruct a scientifically sound understanding of earth's seasons that aligns with scientific evidence. This lesson was designed for a college physical science content course whose population is predominantly elementary education majors. Since inquiry-based learning is emphasized in national standards documents (NRC, 1996; American Association for the Advancement of Science, 1993), this laboratory models inquiry learning for the pre-service elementary teacher.

In this one-group, pretest-posttest (O XO) design, n=151, a pre-test questionnaire was given to students to measure their initial understandings of the reasons for the seasons. The pre-
Seasons 8

post test consisted of two open-ended paper and pencil questions, and the students were given 5-10 minutes to complete the questions. The pre-test was administered at the beginning of the astronomy unit, about two weeks before the Seasons lesson. The post-test questions were integrated into the unit exam. The lesson (Appendix II) was taught to five sections of the course by the same instructor. Each section had a similar student composition of 30-31 students. Three sections met twice per week for 75 minutes, and two sections met three times a week for 50 minutes. A specific effort was made to teach the lesson similarly in each section, even though the class length necessitated some differences in time management.

Pretest – Posttest Question 1

Q. What causes seasons? Why is [university’s location] warmer in our summer and colder in our winter?
A. The Earth's axis having a 23 1/2° tilt with respect to the Earth/Sun plane causes a greater amount of daylight with the Sun having a higher elevation angle in the summer, and a smaller amount of daylight with the Sun being lower in the sky. (The Earth/Sun distance does not affect seasons.) [Instructor’s ideal response]

Pretest – Posttest Question 2

Q2a. Assume the tilt of the earth changed from what it presently to 35°. How would this affect [university’s location’s] summers and winters?
A. Both the summer and winters would be more severe. [Instructor’s ideal response]

Q2b. How would this affect the lengths of hours of daylight and hours of darkness?
A. The daylight would be longer in the summer (nighttime shorter) and the nighttime would be longer in the winter (daytime shorter). [Instructor’s ideal response]

Possible weaknesses

Our university has a planetarium, so the students are able to observe the path of the Sun across the sky for the four astronomically significant days using the concrete model made possible in the planetarium. Since a planetarium is not a common resource, astronomical
software can be substituted when trying to visualize the Sun’s path across the sky as seen from Earth. This two-dimensional model may not be understood as well as the three-dimensional model the planetarium offers.

Our claim of similar administration of this intervention to all five sections is only based on the instructor’s self report. An outside observer would be an advantage to substantiate this claim.

Obviously, this lesson is only useful in Northern Hemisphere mid-latitude locations. The lesson is not applicable as written in the tropics (23 1/2° N to 23 1/2° S) while opposite results occur in the Southern Hemisphere mid-latitudes.

One goal of this lesson is to have pre-service teachers not carry any conceptions that are not scientifically acceptable into their classroom. While many students changed their answers on the post-test to more scientifically accepted conceptions, we do not know how long they retained these conceptions after the intervention.

Results

Results showed statistically significant differences between pre- and post-test results. The first question concerned the causes for seasons. Table 1 shows that the percentage of students receiving zero points (no or an incorrect response) decreased on the post-test from 50 percent to 4.0 percent, while the percentage of students receiving full credit for their answers increased from 31 percent to 93 percent (t = 12.9, v = 277, p<0.005). The mean score increasing from 1.66 to 3.78 (on a 0-4 scale) is a statistically significant improvement.
Table 1.

**Summary of results between pre-test and post-test of Question 1.**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>4 Points</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>128</td>
<td>40 (31%)</td>
<td>6</td>
<td>16</td>
<td>2</td>
<td>64 (50%)</td>
<td>1.66</td>
<td>1.79</td>
</tr>
<tr>
<td>Post-test</td>
<td>151</td>
<td>141 (93%)</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>6 (4.0%)</td>
<td>3.78</td>
<td>0.856</td>
</tr>
</tbody>
</table>

$p < 0.005$

The second question required the application of knowledge of the effect the tilt of the Earth has on seasons. This specific application was not covered in class. During classroom discussion of Mars, the class applied concepts to realize that Mars’ 35° tilt and longer revolution period caused longer and more extreme seasons than the Earth’s. This question, offered as a bonus question, also had statistically significant improvement between the pre- and post-test. Table 2 shows that the percent of students receiving zero points on the post-test (no or incorrect knowledge) decreased from 49 percent to 21 percent, while the percent of students receiving full credit for their answers increased from 13 percent to 46 percent ($t = 5.74$, $v= 277$, $p<0.005$). The mean score increasing from 1.23 to 2.33 (on a 0-4 scale) is a statistically significant improvement.

Table 2.

**Summary of results between pre-test and post-test of Question 2**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>4 Points</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>128</td>
<td>17 (13%)</td>
<td>10</td>
<td>22</td>
<td>16</td>
<td>63 (49%)</td>
<td>1.23</td>
<td>1.46</td>
</tr>
<tr>
<td>Post-test</td>
<td>151</td>
<td>69 (46%)</td>
<td>6</td>
<td>14</td>
<td>30</td>
<td>32 (21%)</td>
<td>2.33</td>
<td>1.68</td>
</tr>
</tbody>
</table>

$p < 0.005$

Discussion

It is well known that teachers tend to teach as they were taught (Tobin, Tippins, & Gallard, 1994). Their experience as learners during their 12 to 16 years as a student have provided many examples of teaching and learning that are not easily displaced. Previous studies
have shown that modeling inquiry in a single methods course is not sufficient for the pre-service teacher to build their understanding of inquiry-based lesson planning (Anderson & Mitchener, 1994). Additional inquiry-based experiences are necessary throughout the teacher preparation program (Tamir, 1989a). Since many of the pre-service teachers who participated in the lessons did not have a clear concept of the seasons before the lesson, the pre-service teachers both learned the content through inquiry and were exposed to inquiry-based teaching methodologies.

The pretest-posttest questions results show that statistically significant improvements occurred in students’ open-ended answers and pre-service teachers conceptions of the reason for seasons improved to scientifically accepted conceptions. Students abandoned non-scientifically accepted conceptions or embraced the scientifically accepted conceptions. This lesson uses concrete evidence at a pre-service teacher’s mathematical level to let the students confront their misconceptions, and with evidence, refute them.

This lesson provides an opportunity for the teacher to uncover student’s misconceptions, and for students to use real astronomical data to calculate the possible amount of solar radiation that a mid-latitude location can receive during the year. The problem, usually solved using integral calculus, is simplified to one that uses middle school mathematics to graphically calculate these amounts while maintaining the mathematical significance of the results.

This paper shares an effective, innovative approach to teaching prospective elementary teachers about seasons within the context of a college science content course. An abstract, three-dimensional problem dealing with the Earth rotating while revolving around the Sun can be distilled down to a back-of-the-envelope problem using basic mathematics such as calculating the area of a triangle. Students use actual astronomic data to compare radiation received on the solstices and equinoxes, taking the Earth-Sun distance into account. This lesson provides
concrete evidence that the reason for seasons in the mid-latitudes is not the changing distance from the Earth to the Sun.

This presentation is a clear example of how an inquiry-based laboratory can examine a familiar phenomenon with common misconceptions, can provide concrete data as evidence and allow the students to understand and explain their reasons for the phenomenon. This lesson has been successfully used in undergraduate physical science courses designed for non-majors and may be used in a college setting from small classes to large lecture halls. It only requires a calculator that calculates the sine of an angle, graph paper, and a student’s understanding of the problem.
References


## Appendix I

### 5E / Inquiry Lesson Planning Model

<table>
<thead>
<tr>
<th><strong>ENGAGE</strong></th>
<th>What the teacher is doing -</th>
<th>What the student is doing -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students engage with a scientific question, event, or phenomenon. This connects with what they already know, creates dissonance with their own ideas, and/or motivates them to learn more.</td>
<td>- Identifies what the students know/think about the subject - Generates curiosity - Raises questions</td>
<td>- Generates explanations - Compares their understandings with their peers - Asks - &quot;What do I think about it?&quot;, &quot;How does that work?&quot;</td>
</tr>
<tr>
<td>e.g. Discrepant event demonstration, discussion of picture, question, story</td>
<td>- Does NOT provide explanations or give definitions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>EXPLORE</strong></th>
<th>What the teacher is doing -</th>
<th>What the student is doing -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe. Guided inquiries, skill building labs, database analyses</td>
<td>- Provides time for students to puzzle, think - Observes students as they interact - Asks probing, open-ended questions - Acts as a consultant</td>
<td>- Tests predictions and hypotheses - Forms new predictions and hypotheses - Builds evidence-based explanations - Critically listens to other explanations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>EXPLAIN</strong></th>
<th>What the teacher is doing -</th>
<th>What the student is doing -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students present, explain, and clarify their understandings and explanations of concepts, and compare them with teacher’s and other sources of scientific knowledge.</td>
<td>- Encourage students to explain their ideas in their own words. - Asks for justification based on evidence, and further clarification - Formally provides definitions, explanations, and new labels and vocabulary - Checks for understanding</td>
<td>- Explains possible solutions - Defends their ideas with evidence-based arguments - Questions other explanations - Listens to and tries to understand teacher’s explanations - Links new vocabulary to their understanding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>ELABORATE</strong></th>
<th>What the teacher is doing -</th>
<th>What the student is doing -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students extend their new understandings and abilities and apply what they have learned to new situations.</td>
<td>- Asks students to use their new ideas and skills in a different situation - Expects students to use formal definitions and explanations</td>
<td>- Uses new concepts, skills, definitions and labels in different situation or to solve a new problem. - Checks for understanding with peers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>EVALUATE</strong></th>
<th>What the teacher is doing -</th>
<th>What the student is doing -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students, with their teachers, review and assess what they have learned and how they have learned it.</td>
<td>- Observes students as they apply new concepts - Looks for evidence that students have changed their understandings - Allows students to assess their own learning and skills Asks open-ended questions such as: “Why do you think? What evidence do you have? How would you explain?”</td>
<td>- Demonstrates understanding or knowledge of the concept/skill - Answers open-ended questions by using observations, evidence, and scientifically accepted explanations - Asks related questions that would encourage future investigations</td>
</tr>
</tbody>
</table>
Appendix II

What causes seasons on Earth?

Lesson Goals:
- The students will understand that the sun is at the farthest point in its’ orbit during the warmest seasons.
- The students will understand that the tilt of the Earth’s axis results in varying amounts of light energy reaching the Earth’s surface and variations in the length of daylight experienced by different latitudes.

Correlation to the National Science Education Standards:

Content Standard A: Science as Inquiry, Grade Level: 12
- Abilities necessary to do scientific inquiry
  - Formulate and revise scientific models
  - Recognize and analyze alternative explanations and models
  - Communicate and defend a scientific argument
- Understandings about scientific inquiry
  - Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence.

Content Standard D: Earth and Space Science
- Earth in the solar system
  - Seasons result from variations in the amount of the sun’s energy hitting the surface, due to the tilt of the earth’s rotation on its axis and the length of the day.

Lesson Objectives: At the conclusion of this lesson, the student will be able to:
- Using a model of the earth and a light source for the sun, collect observational evidence
- Analyze astronomical data and justify their explanations in light of this evidence
- Construct an explanation for the seasons of the Earth based on evidence.
- Communicate their ideas to the class and defend their reasoning
- Analyze other students’ arguments for logical relationships to the evidence.

Plain paper    graph paper
Pencils        rulers
Large globe    calculators
overhead transparency of a “side view” of the earth’s orbit from a text
laser pointer
Procedure: ENGAGE:

1. Ask students to draw a picture and write a short paragraph that explains their understandings of the reason we have seasons.

2. Construct a class list on board: compare various ideas and ask for supporting evidence and arguments.

3. Expect to get correct answers and incorrect answers, along with answers that don't address the lesson emphasis (for example, the position of the jet stream, global warming!).

4. Discrepant event:
   a) Discuss tanning during Spring Break! Why do people in Florida tan (or burn!) better than students who stay on campus. Discuss – If the Earth is in the same relative position with respect to the Sun, the two locations should receive the same solar radiation. Ask the students to list any new questions, e.g. Why is Florida in March like Ohio in June?

EXPLORE:

1. Collect first data set:

5. Ask: What are the dimensions of Earth’s orbit? Is it a circle or an ellipse? Draw a circle and an ellipse on board.

6. Ask: Which figure best represents the Earth’s orbit?

7. Show a diagram that represents the actual orbit shape. Give #’s from text or other resource (or have students find them in text).
   
   152 million km - farthest point, (in July), 147 million km - closest point (in Jan.)

8. What shape results? (While elliptical, egg-shaped, with July at the farthest point, it more resembles a circle!)

9. Does this make sense to you? Why or why not? How does this agree with your previous ideas?

10. Show the cigar-shape orbital diagram from a textbook on the overhead.

11. Have you seen a diagram like this before? (Commonly included in elementary textbooks.) Has it influenced your ideas? How would a second-grader interpret this diagram?

12. What can you now say about the perspective of this diagram?
Second Data Collection:

13. Using a large globe, ask the students to join you in reviewing the position of the major latitudes, poles, Tropic of Cancer and Tropic of Capricorn, and equator.

14. Holding the globe, tell the seated students that they represent the Sun (because they are so bright!) and walk around them with the axis pointed at some distant star. Since the students are the Sun, any part of the Earth that they can see with their eyes would be the same parts of the Earth that they would radiate upon. If they don't see it, they can't shine on it.

15. Using an axis tilt of $0^\circ$, ask the students to define daylight and darkness areas on the Earth. Ask them to sketch and label the areas.

16. Using an axis tilt of $50^\circ$, repeat the walking around the students, and again ask them to diagram what they see – where is the daylight and dark?

17. Finally, use an axis tilt of $23\,1/2^\circ$. Making Polaris above and behind the Sun (students), lead them to see that they can see the North Pole during a whole rotation, some parts of the earth only during part of a rotation, and some parts of the Earth, not at all.

18. I'll draw on the chalkboard what the sun sees on this day, the entire Arctic Circle, and none of the Antarctic Circle. Ask the students to compare the instructor’s drawings with their own.

19. The class will figure out where the center of their view of the globe is, and at that point the sun's rays are perpendicular to the surface of the earth (where the sun is at the zenith). The instructor can point a laser pointer at the dead center, and the students close to the globe read the latitude. For this day the Sun is at the zenith at local noon on the Tropic of Cancer. We will draw the other important latitudes on the chalkboard.

20. The Earth will revolve one quarter of a revolution and go the fall equinox (not yet defined). The Sun will be able to "see" every point on the globe during a rotation, and the sun will be at the zenith at local noon at the Equator.

21. The Earth will revolve one quarter of a revolution to the Winter Solstice (not yet defined), where the Arctic Circle is not visible and the entire Antarctic Circle is visible. Again we draw the important latitudes on the board.

22. Repeat for the Spring Equinox (not yet defined), and continue back to the summer solstice.

23. Students now construct a claim that represents their understandings thus far, and is based on their data collections and drawings. Construct a drawing of the Earth’s orbit and label the seasons. Prompt them to see the difference between spring/fall shadow configurations and the summer/winter shadows. Ask them to list two pieces of evidence that their explanation is based upon.
EXPLAIN:

24. Ask a few students to share their claims with the class, and explain their evidence. Ask them to explain how they decided which season was which. *(Equal time of daylight and night, hemispheres toward sun, etc.)*

25. For each diagram, an “X” is placed by the student for the location of the University. Draw a dotted path on a globe diagram to represent the path traced by our location as the Earth turns on its axis. A longer path represents longer daylight hours in summer, and a shorter path represents winter’s shorter time of daylight.

26. We'll note that the line in June is the longest, in fact we'll declare that this is the day where the daytime is the longest and define that as the Summer Solstice. This is also the longest day for any point in the Northern Hemisphere, shortest for the Southern Hemisphere.

27. Noticing that the December picture has our location on the shortest path, and since the Earth rotates at a constant pace, as shorter path would mean less time the sun can "see" that location, this day is defined as the Winter Solstice, the day where the Northern Hemisphere has the shortest amount of daylight, and the longest amount of daylight for the Southern Hemisphere.

28. Fall and spring days are defined as equinoxes, where the word means “equal night”, so every location has 12 hours of daylight, 12 hours of darkness. Clarify the terms rotation, revolution, direct and indirect light, aphelion, perihelion

GOING FURTHER:

29. I also take the students to the planetarium for a similar explore and explain in the where the students are seeing this from the Earth's point of view, instead of from the Sun’s.

ELABORATE:

30. Students apply their new understandings in two activities that analyze additional evidence and more opportunities to construct a deeper understanding. (See below.)

EVALUATE:

1. What causes seasons? Why is [university’s location] warmer in our summer and colder in our winter?

2. Assume the tilt of the earth changed from what it presently to 35°. How would this affect [university’s location’s] summers and winters?

3. How would this affect the lengths of hours of daylight and hours of darkness?
Elaborate Activity

Incoming solar radiation at 41° N.

It is obvious that summers are warmer and winters are colder at this latitude. Astronomically speaking, the length of daylight is longer in the summer and shorter in the winter, and the sun’s elevation at noon varies also. It is highest on the summer solstice and lowest on the winter solstice, while it is in the middle of these two extremes on the equinoxes.

Today’s activity will be to graphically calculate the amount of solar radiation that comes to this latitude on the winter solstice, the spring equinox, the summer solstice and the fall equinox. Secondly, we will calculate the amount of solar radiation received a certain day of each month.

We will assume that the sun gives this location 0 watts of radiation at sunrise and sunset. On the equinoxes, the sun will be at (90° - our latitude) at solar noon. The sun will be 23 1/2° higher than this on the summer solstice and the sun will be 23 1/2° lower on the winter solstice. Since our location is at 41° North latitude, the sun will be at the following angles at solar noon:

<table>
<thead>
<tr>
<th>Season</th>
<th>Angle</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter solstice</td>
<td>26°</td>
<td>(December 21)</td>
</tr>
<tr>
<td>Spring equinox</td>
<td>49°</td>
<td>(March 21)</td>
</tr>
<tr>
<td>Summer solstice</td>
<td>72°</td>
<td>(June 21)</td>
</tr>
<tr>
<td>Fall equinox</td>
<td>49°</td>
<td>(September 21)</td>
</tr>
</tbody>
</table>

Solar noon is different than 12:00 noon Eastern Standard Time or 12:00 noon Eastern Daylight Time. Solar noon is when the sun is at its highest elevation and it is due south (making all shadows due north).

We will assume a cloudless, atmosphere-less location, so no incoming solar radiation will be scattered or reflected. We will also assume that the earth is exactly 1 AU away from the sun during the entire year. The solar constant, the amount of solar radiation the earth receives above the atmosphere, when the earth is 1 AU from the sun, and at a right angle to the sun, will be assumed to be 1360 watts/square meter.

The amount of radiation received is proportional to the sine of the sun’s angle of elevation. Radiation = 1360 w/m² × sin θ, where θ is the sun’s elevation angle.

For example, if the sun was in the zenith (90°) the Earth would receive sine 90° × the solar constant, (1.00 × the solar constant = 100% × the solar constant = 1360 w/m²). Likewise, if the sun was on the horizon (0°) the Earth would receive sine 0° × the solar constant, (0.00 × the solar constant = 0% × the solar constant = 0 w/m²).

We can graphically calculate the amount of solar radiation we receive in a day by plotting three data points: sunrise, sunset, and local noon. Then we draw a line connecting the three points and determine the area under the “curve”.

Seasons 22

Winter solstice

1) Sunrise is approximately 7 am and sunset, 5 pm. What is the angle of elevation for the sun at these times?  
   What is the amount of solar radiation at sunrise? Sunset?  
   Plot these values on your graph paper at 7 am and 5 pm.
2) What is the angle of elevation for the sun at solar noon? (see chart above)  
   What is the amount of solar radiation?
   Plot this value on your graph paper at 12 noon.
3) Connect the three points. Shade in the area under the two lines. Calculate the area you shaded. (Hint: The area should be a triangle where the formula for area is $A = \frac{1}{2} bh$) Make sure you use proper units.  
   This area is the amount of solar radiation that hits our location on the winter solstice.

Spring equinox

1) Sunrise is approximately 6 am and sunset, 6 pm. Plot the amount of solar radiation received on your graph paper at 6 am and 6 pm.  
   What is the angle of elevation for the sun at solar noon? (see chart above)  
   What is the amount of solar radiation?  
   Plot this value on your graph paper at 12 noon.
3) Connect the three points. Shade in the area under the two lines. Calculate the area you shaded. This area is the amount of solar radiation that hits our location on the spring equinox.

Summer solstice

1) Sunrise is approximately 5 am and sunset, 7 pm. Plot the amount of solar radiation received on your graph paper at 5 am and 7 pm.  
   What is the angle of elevation for the sun at solar noon? (see chart above)  
   What is the amount of solar radiation?  
   Plot this value on your graph paper at 12 noon.
3) Connect the three points. Shade in the area under the two lines. Calculate the area you shaded. Make sure you use proper units.  
   This area is the amount of solar radiation that hits our location on the summer solstice.

Fall equinox

Which of these graphs (if any) accurately depicts the amount of solar radiation received on the fall equinox?
Incoming solar radiation at 41° N, Part 2.

We saw in our last lab that the amount of solar radiation received at this latitude can vary by almost 300% between winter and summer. Our model was very simple: we ignored clouds or atmospheric scattering, we assumed that the amount of radiation received between sunrise and noon and also noon and sunset varied linearly (we drew a straight line between the points). We also assumed that the distance between the Sun and Earth was constant.

The most common misconception for the cause of seasons is the distance between the Earth and Sun. One often thinks of the Sun as a “fire in the sky,” and in the summer the Earth receives more radiation and the Sun feels hotter. Since one gets more radiation when one gets closer to a fire, one can imagine that the reason the Sun feels hotter is because the Earth is closer to the Sun in the summer. Unfortunately, this “common sense” analogy is wrong.

We will redo your last astronomy lab today, except we will take the Earth/Sun distance into account. The revised formula for finding the amount of radiation received is:

\[
\text{Radiation} = (1.000 \text{ AU/Earth-sun distance})^2 \times 1360 \text{ w/m}^2 \times \sin \theta,
\]

where \( \theta \) is the sun’s elevation angle.

In our last lab, we assumed the Earth/Sun distance was 1.000 AU, so the first term was \((1.000 \text{ AU}/1.000 \text{ AU})^2 = 1 \). Now we will “tweak” our results and make them more accurate.

**Procedure:**

1. Redo the last lab, plotting the values of incoming solar radiation at sunrise, local noon and sunset, and calculate the total amount of radiation received (power) over the day.

<table>
<thead>
<tr>
<th></th>
<th>Sunrise</th>
<th>Sunset</th>
<th>Angle of elevation at noon</th>
<th>Earth/Sun distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter solstice</td>
<td>7 AM</td>
<td>5 PM</td>
<td>26°</td>
<td>0.984 AU</td>
</tr>
<tr>
<td>Spring equinox</td>
<td>6 AM</td>
<td>6 PM</td>
<td>49°</td>
<td>0.996 AU</td>
</tr>
<tr>
<td>Summer solstice</td>
<td>5 AM</td>
<td>7 PM</td>
<td>72°</td>
<td>1.016 AU</td>
</tr>
<tr>
<td>Fall equinox</td>
<td>6 AM</td>
<td>6 PM</td>
<td>49°</td>
<td>1.004 AU</td>
</tr>
</tbody>
</table>
**Results**

<table>
<thead>
<tr>
<th></th>
<th>Daily amount of solar power received</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>this lab</td>
</tr>
<tr>
<td></td>
<td>last lab</td>
</tr>
<tr>
<td></td>
<td>percent difference</td>
</tr>
<tr>
<td>Winter solstice</td>
<td>____________</td>
</tr>
<tr>
<td>Spring equinox</td>
<td>____________</td>
</tr>
<tr>
<td>Summer solstice</td>
<td>____________</td>
</tr>
<tr>
<td>Fall equinox</td>
<td>____________</td>
</tr>
</tbody>
</table>

(percent difference = \[\{\text{this lab}/\text{last lab}\} \times 100\%] – 100\%)

1. If the Earth revolved around the Sun in a circular orbit at a constant distance of 1.000 AU (like we calculated last lab), would this latitude receive more or less radiation at the summer solstice than it presently receives because of its elliptical orbit (this lab)?

   Would we be warmer or cooler with a circular orbit with a distance of 1.00 AU?

   Would we receive more or less radiation at the winter solstice?

   So would we be warmer or cooler?

2. Using your results from your last lab, what percentage more/less radiation was received on the summer solstice than the winter solstice?

   **Percent difference = \[((\text{summer solstice}/\text{winter solstice}) \times 100\%) \, - \, 100\%\)**

3. What percentage more/less radiation was received on winter solstice when you took the Earth/Sun distance into account? (Answer is in the table above)

4. Was the answer in Question 2 or Question 3 larger?

   Which factor do you think is more important in seasons, the Earth/Sun distance or the different lengths of daylight and changing sun’s elevation angle caused by the Earth’s tilt?