PCK Tools

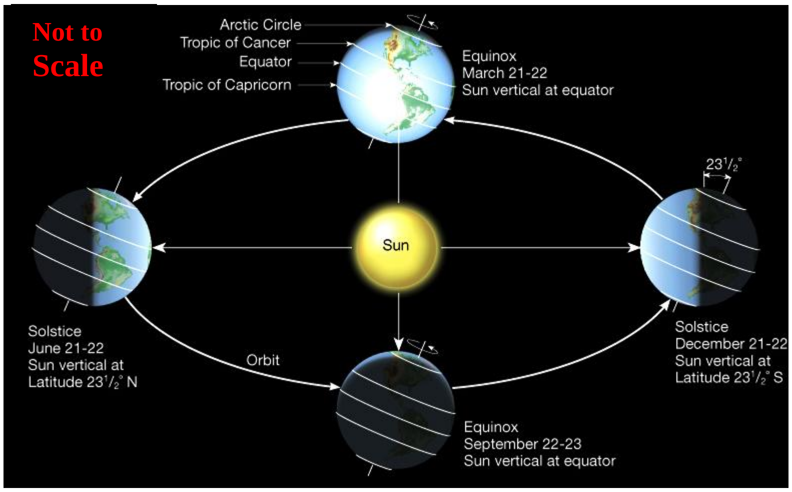
Seasons: Student Misconceptions and Strategies for Teaching

Students from middle school even to the college level have difficulty explaining the reasons for the seasons, despite the fact that most students at some point have received instruction on the subject in school. The good news is that there is a significant amount of research regarding student misconceptions about the causes of the seasons. Teachers can utilize this research to get a good understanding of what students coming into their classrooms will be thinking. In addition, there are a couple of studies with very specific strategies for bringing students to a better understanding of the causes of the seasons.

What Causes the Seasons?

The seasons are caused by a combination of factors involving several scientific concepts. Students must not only understand the Earth's tilt and orbit around the Sun but also how the tilt and orbit interact to create changes in the amount of the Sun's radiation reaching a particular location. Understanding this is made more difficult by the need to be able to "see" the system from different perspectives.

First, the Earth is a sphere that takes one full year to orbit the Sun. Second, the Earth spins on its axis, an imaginary rod that passes through the North and South Poles. Each complete spin takes one day and results in the day/night cycle. Third, this axis is tilted with respect to the plane of the Earth's orbit, aiming always in the same direction, toward the North Star, an average of about 23.5 degrees relative to the ecliptic, the plane of the Earth's orbit. As the Earth orbits the Sun, its axis pointing always in the same direction, different places on the Earth (e.g., Northern Hemisphere or Southern Hemisphere) encounter sunlight at different angles and receive different intensities of radiant energy from the Sun. When the Northern Hemisphere is pointed away from the Sun, it receives less radiant energy from the Sun and it experiences winter. When the Northern Hemisphere is pointed toward the Sun, it experiences summer because it receives more radiant energy from the Sun. Note that when we say the Northern Hemisphere is pointed towards the Sun, this does not mean that the Northern Hemisphere is closer to the Sun, but rather the angle at which the Northern Hemisphere encounters the Sun's rays is steeper. Spring and fall occur between these two extremes.



Note that the scale in this image is completely off. The Sun is massive and much bigger than the Earth. In addition, the Earth is much, much farther from the Sun than this image suggests; thus, even though the Earth is tilted, the Northern Hemisphere is not physically closer to the Sun than the Southern Hemisphere during the summer (what is more important is the angle that the sun's rays hit the northern hemisphere—when the northern hemisphere is tilted towards the sun, the sun is higher in the sky so the sunlight we receive is more concentrated). Also, while the orbit of the Earth around the Sun is an ellipse, it is nearly a circle and therefore its distance from the Sun at different times in its orbit is very similar at all points in the year (this image exaggerates the distance of the Earth from the Sun during spring and fall compared with winter and summer). Thus, while images like these can help to clarify some concepts, they also can be misleading.

State Standards

On the topic of seasons, **New Jersey Core Curriculum Content Standards for Astronomy and Space Science** hold the following expectations of what middle school students should learn about and be able to do:

6th grade

- Recognize that changes in the Earth's position relative to the Sun produces differing amounts of daylight seasonally.

8th grade

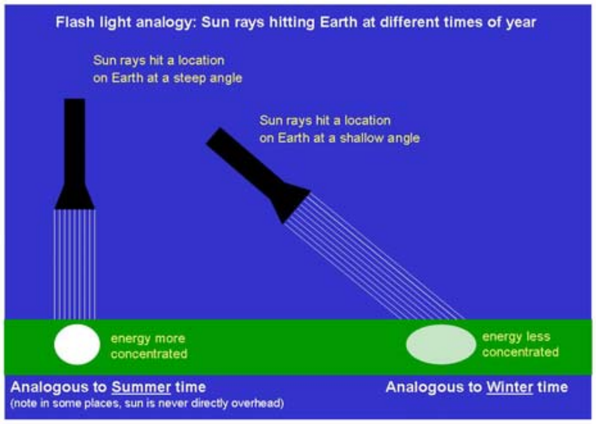
- Explain how the tilt, rotation, and orbital pattern of the Earth relative to the Sun produce seasons and weather patterns.

The Texas Essential Knowledge and Skills (TEKS) standards set these expectations for middle school students:

- Identify and illustrate how the tilt of the Earth on its axis as it rotates and revolves around the Sun causes changes in seasons and the length of a day.

To understand how this tilt causes the seasons, consider the following experiment. Imagine shining a flashlight on a table. When the flashlight is perpendicular to the table, you see a circle of light.

If the flashlight is held at an angle to the table, the circle of light spreads over a larger area, forming an oval. The same amount of light is reaching the table but it is spread over a larger area so the amount of light reaching any specific point is less. This is similar to how radiation from the Sun impacts the Earth. When one hemisphere of the Earth is pointed away from the Sun, the Sun's radiation is more spread out or less concentrated. When that same hemisphere is pointing toward the Sun, the radiation is more concentrated. What we observe from Earth is that the Sun is higher in the sky during the summer months and lower in the sky during the winter months.



Adapted from Gary Becker, www.astronomy.org/programs/seasons

A smaller seasonal effect results from the fact that the days are longer in the summer—also a result of the tilt—and therefore we receive more of the Sun's energy in one day than we do when the days are shorter in the winter. The higher and longer path of the Sun in the sky is during the summer months, and the longer the day, the more radiant energy is received from the Sun.

For a more detailed description of the seasons, see:
http://www.physicalgeography.net/fundamentals/6h.html

What Problems and Common Misconceptions Do Students Have About the Causes of the Seasons?

The most common explanation students give for what causes differences in the seasons is that it depends on the Earth's distance from the Sun. Most often, students describe the distance in general terms, that is, the Sun is farther away in winter than it is in summer. In reality, the Earth is actually closest to the Sun in January when the Northern Hemisphere is experiencing winter, so the very slightly elliptical nature of the Earth's orbit cannot cause the difference in seasons. Sometimes, the distance that students cite as a cause is the tilt of the Earth—the part experiencing winter is tilted away from the Sun and therefore farther away from the Sun. Again, this change in distance is not large enough to cause the seasons. The prevalence of these misconceptions has been noted in numerous studies.

Perhaps the most publicized study is the video project called "A Private Universe" (Schneps, 1987). In the video, Schneps interviewed Harvard graduates, staff, and faculty on the day of commencement and asked them why it is hotter in summer than it is in winter. Of the 23 people interviewed, only two gave an acceptable explanation. The most common explanation given by the students interviewed was a general statement about the Earth's distance from the Sun.

Atwood and Atwood (1996) found similar results when they asked preservice teachers about the cause of the seasons using both a written instrument and individual interviews using a model representing the Earth and the Sun. Only one student of 49 correctly identified the cause of the seasons on the written task as well as in the individual interview. For the written task, the following alternative conceptions were offered:

- the distance of the Earth from the Sun (18 students),
- the closeness of part of the Earth due to the Earth's tilt (6 students),
- the rotation of the Earth on its axis (4 students), and
- the way the Earth is positioned on its axis; the part facing the Sun is having summer (4 students).

The remaining students gave incomplete or unclear responses. Note that roughly half of the students on the written task related the changing seasons to distance, either in general terms or as a result of the Earth's tilt. Following the written task, students were interviewed with models of the Earth and Sun available to them. The sphere representing the Earth had a wooden dowel rod inserted through the center and into one of two holes in a small wooden block. When the dowel rod was inserted in one hole, the rod and model of the Earth stood perpendicular to the horizontal surface. When the rod was inserted into the other hole, the rod and model of the Earth stood tilted approximately 23.5 degrees from perpendicular. Interestingly, when students were interviewed, 38 of the 49 selected the tilted model of the Earth to demonstrate the cause of the seasons. While they were aware of the Earth's tilt, this awareness did not translate into an understanding of the cause of the seasons. Following is a list of the alternative conceptions identified:

- the distance of the Earth from the Sun (19),
- the direction of the Earth's tilt changing as the Earth revolves around the Sun (7),
- the rotation of the Earth on its axis (6),
- the pole of the hemisphere having summer being pointed almost directly toward the Sun (4), and
- the Sun revolving around the Earth (3).

An interesting side note to this study is that very few students used the same alternative conception on both the written and verbal tasks. The authors suggest that perhaps this is a sign that students do not have strongly held alternative conceptions.

The largest study of students' astronomical understanding was undertaken by Sadler (1992). Sadler administered a 47-item multiple-choice test to 1,250 students in 22 classrooms ranging from 8th to 12th grade both before and after instruction. Each question contained five responses—the scientifically correct response together with four representing alternative conceptions.

The question relating to the cause of the seasons follows:

> The main reason for its being hotter in summer than in winter is:
> A. The Earth's distance from the Sun changes.
> B. The Sun is higher in the sky.
> C. The distance between the Northern Hemisphere and the Sun changes.
> D. Ocean currents carry warm water north.
> E. An increase occurs in "greenhouse" gases.

The correct answer (B) was chosen only 12% of the time. Answer A was selected 45% of the time and answer C 36% of the time so that a total of 81% of the time students selected a reason related to distance. Based on the pre- and post-instruction results, one year of science appeared to do little to change this belief.

In a related question, students were asked:

> How often is the Sun directly overhead at noon in your hometown?
> A. Every day.
> B. Only in the summer.
> C. Only for the week of the summer solstice.
> D. Only for one day each year.
> E. Never.

This test was only given to students in the continental United States, so the correct answer is E. Even though the Sun is higher in the summer, it is never directly overhead in the United States. Forty-one percent of students chose A, and only 18% chose E. For those students who believe that the Sun is directly overhead at noon every day, relating the seasons to the changing position of the Sun in the sky (for the question about the seasons) would be a difficult concept. Together, the two questions reveal that students have not observed the pattern of the Sun across the sky over the course of the year.

DeLaughter and colleagues (1998) had similarly dismal results when they asked 149 students in a college-level introductory Earth science course open-ended questions about the cause of the seasons. They reported that only 17% of the students attributed the different seasons to the tilt of the Earth's axis.

While none of the above studies examined how students arrive at their theory that distance from the Sun affects the season, it is possible that students are told of the Earth's elliptical orbit around the Sun and later attribute the cause of the seasons to this elliptical orbit, despite the fact that the elliptical nature of the orbit is so small as to not have an impact. As the video "A Private Universe" (Schneps, 1987) shows, many textbooks contain illustrations that show exaggerated eccentricities of the Earth's orbit. Similarly, students are introduced to the notion that the Earth rotates on its axis early in school and students may mistakenly conclude that this causes the seasons.

Key Points on Student Misconceptions: Seasons

- A majority of students believe the seasons are somehow caused by distance. In many cases, students believe the distance is due to an elliptical orbit, i.e., the Earth must be farther away in winter than it is in summer.
- In some cases, students believe the distance is due to the Earth's tilt—the hemisphere that is tilted away from the Sun is farther away and therefore experiencing winter.
- Less widespread, though nonetheless present among some students, is the notion that the rotation of the Earth around its axis causes the seasons.

Some Strategies to Address Student Misconceptions About the Cause of the Seasons

A number of instructional techniques common to all science instruction can be helpful during lessons on the seasons.

Identify and Confront Misconceptions

Whether they are called alternative frameworks or life lessons, the knowledge that students have acquired through their own experiences must be identified and addressed. According to Drier, et al. (1994), science teachers at the secondary level "need to be aware of pupil's existing ideas, of the learning goals, and also of the nature of any differences between the two" when they are planning for and implementing science lessons. The first thing to do is consider the nature of any differences between children's prevalent thinking and the scientific viewpoint. Once the teacher has identified the nature of any differences between the pupil's thinking and the scientific viewpoint, it becomes easier to plan the lesson and related activities. In some cases, students may have trouble with the new scientific notions being expressed; time will be needed for the students to come to terms with a concept that is foreign to them.

Bridge the Gap

Instruction should not only provide information on the basic concepts but should also connect those understandings to issues in everyday life. Students must be given an opportunity to express what they understand about the seasons before formal instruction begins. With this as the focus, Duit and Haeussler (1994) argue that we must “reject the idea of replacing students’ conceptions with scientific ones. If we were to try, students would learn a conception that is at least partly contradictory to the life-world conceptions.”

Indeed, Gilbert, Osborne, and Fensham (1982) propose a number of outcomes that might result from teaching if students are not able to bridge the gap between life experience and the scientific view:

- *Undisturbed outcome*: Students retain their intuitive ideas.
- *Dual perspective*: Academic and intuitive ideas coexist; students use their intuitive ideas except in the classroom.
- *Incorrectly reinforced outcome*: Some scientific ideas have been absorbed, but used incorrectly to justify intuitive ideas.
- *Mixed reaction*: Academic ideas have been learned, but not totally integrated; students may use either academic or intuitive ideas for similar problems.
- *Unified outcome*: Students have learned the material and integrated it into their cognitive structures, presenting a scientific view of the world.

Concept Mapping

Concept mapping was developed by Novak and Gowin (1984), and it is a technique that has been shown to have a positive effect (Horton, et al., 1993) on students’ understanding of science. Essentially, children are given 6-10 relevant words, each written on a small square of paper. The students then construct a diagram where related terms are placed close to each other. Relations are shown by linking terms with lines, and sentences are added to the lines to show what the relationship is. If the mapping activity is done by groups of students, they are forced to justify their choices in arranging the terms and to articulate their own understanding.

Conceptual Change as Evolutionary

Big conceptual changes are often *evolutionary*, involving a gradual process, rather than revolutionary in nature (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). This suggests that students’ learning progresses from initial, scientifically more or less incorrect views via some intermediate or “transitional state” towards the scientific perspective (Thornton, 1995). Conceptual change on the part of students requires time and explicit attention to developing the concepts (Savinainen, et al., 2005).

Posner, Strike, Hewson, and Gertzog (1982) contend that a number of conditions must be met in order for conceptual change to occur: (1) students must become dissatisfied with their existing alternative conception because of new data (sometimes referred to as anomalous data) that the conception cannot accommodate; and a new conception must be (2) intelligible, (3) plausible, and (4) fruitful. Not only do students need to make sense of the new conception, they also must be able to apply it to new situations.

Specific Strategies for Teaching About the Seasons

While a fair amount of attention has been paid to students' and teachers' misconceptions about the causes of the four seasons, less attention has been focused on specific strategies for teaching the concepts to students. There are, however, a few good places to start.

Observation

An obvious place to start would be with the information provided by Sadler's study that a majority of students believe the Sun is directly overhead every day of the year. Ask students this same question and then have them observe the Sun in the sky over a period of months leading up to instruction about the seasons.

Conflict Maps

Another good resource is a study by Tsai and Chang (2005) in which they created a conflict map theory for instruction consistent with Posner, et al.'s theory of conceptual change and applied their interpretation of the model to the teaching of the seasons. Based on the results of their study, teachers could implement very specific strategies that Tsai and Chang found to be more successful than traditional teaching.

In their conflict map theory, students must resolve two conflicts during the course of instruction, one between a new perception and students' alternative conception (conflict 1), and the other between student's alternative conception and the scientific one (conflict 2). Conflict 1 may be resolved through discrepant Earth events wherein students are confronted with an unfamiliar fact (in this case, the fact that the Earth is slightly farther from the Sun in June and July than it is in December and January) and conflict 2 should be resolved using "critical events or explanations"—making inferences that contradict a fact well known to them (in this case, if seasons were caused by the Earth's distance to the Sun, the Northern and Southern Hemispheres would have the same season at the same time). In addition, other relevant conceptions and perceptions are used to support the target scientific conception.

For their study, Tsai and Chang interviewed 50 students randomly selected from two classrooms of 9th graders learning about the cause of the seasons. In one classroom, students learned about the seasons using the conflict map model for instruction. In the second classroom, students learned from the same teacher using a traditional approach to instruction. Students were interviewed one week, two months, and eight months after instruction.

The conflict-map model of instruction consisted of the following sequence over the course of two 50-minute class periods, according to the researchers:

> In the first period, the teacher first reviewed the concepts of rotation and revolution, then asked students to explain the possible causes of the seasons. The students then worked in small groups to discuss possible explanations. Students presented their ideas to the whole class, and the teacher finally introduced a discrepant event (i.e., in June and July, the Earth is slightly further from the Sun, whereas in December and January, the Earth is closer to the Sun). The teacher further used the following critical event to challenge students' alternative conceptions (i.e., if seasons were caused by the Earth's distance to the Sun, the Northern and Southern Hemispheres would have the same season at the same time). The teacher ended the instruction at this point for students to think more about other contradictions and alternatives.
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> In the second period, the teacher first reviewed the discrepant and critical events presented in the first period. After listening to more students' ideas, the teacher gave a scientific explanation that seasons are caused mainly by the Earth's 23.5° tilt of axis. This part of the instruction used some balls of different sizes and role-playing activities to explain the possible relationships between the Sun and the Earth. The teacher then related the target scientific concept to other scientific concepts, such as revolution, rotation, Tropic of Cancer, and Tropic of Capricorn, coupled with the conclusions drawn from the discrepant and critical events. Finally, the teacher used other perceptions to support the target scientific concept, such as the length of day and night, the "warm" Christmas in Australia and New Zealand, and the possible seasons on other planets. (pp. 1097-1098)

Traditional instruction emphasized direct guidance, lectures, demonstration, and classroom discussion. Specifically:

> In the first period, the teacher gave a review about rotation and revolution. He then directly gave a scientific model to explain the causes of seasons. Similar to that in the conflict map group, this part of the instruction used different sizes of balls, role-playing activities, and group discussions to explain the possible relationships between the Sun and the Earth.
>
> In the second period, the ideas of tropic of Cancer and Tropic of Capricorn were introduced and emphasized. The teacher then guided the students to finish some tutorial problems and a quiz in the textbooks. Students applied their knowledge about the causes of seasons to solving these problems and the quiz.

In the first interview, 68% of students in the traditional group and 76% of students in the conflict map group expressed scientific conceptions about causes of the season. In the second interview, these numbers dropped to 40.9% in the traditional group and 65.2% in the conflict group. By the third interview (8 months after instruction), the numbers dropped to 22.7% in the traditional group and 54.5% in the conflict map group. More than twice as many students in the conflict map group remembered the cause of the seasons 8 months after instruction.

Equally interesting is a breakdown of the students who were able to state the scientific conception. A detailed analysis over time of the students, who in the beginning were able to state the cause of the seasons without any further explanation (labeled as "fact" in the study), showed that those students were much more likely to revert to their original alternative conception over time. Additionally, more students who learned through the traditional model fell into this "fact" category than those students who learned through the conflict map model. The authors caution that teachers should pay particular attention to those students who are able to recite the correct response, as was the case here, but don't appear to truly understand the phenomena. These same students will likely revert to their original alternative conceptions as most of them did in this study.

While the Tsai and Chang study is small, it does support the notion that students need to "wrestle" with their alternative conception—need to be given some sort of anomalous data that does not fit; once they are provided with a scientific conception that is understandable and plausible, they should be allowed to apply the scientific concept to new information.

Modeling

The final recommendation comes from a study by Callison and Wright in which they studied the impact of modeling for teaching about the lunar phases. While the study was not specifically about the seasons, it is true that both lunar phases and the seasons require learning concepts that are not directly visible and are difficult to see as a complete system. To help understand this type of scientific phenomena, Callison and Wright argue that providing physical models during instruction will help students develop an explanatory model, and this is supported by their study. Seventy-six students in four different groups were taught using four different teaching strategies. Three of the teaching strategies utilized physical models while the fourth required the students to develop a mental model in the absence of a physical model. There was a significant shift along the spectrum from no model (no understanding of the lunar phases) to a correct or scientific model of the lunar phases for those students in the three classrooms that utilized physical models. There was not a significant shift along the spectrum in the classroom that did not utilize physical models. Like the Tsai and Chang study, this study is small but does support what many would argue makes intuitive sense—it is easier to learn something you are unable to visualize by providing concrete models to understand the processes involved.

Seasons: Lessons Learned

Understanding the causes of the seasons requires an understanding of multiple scientific conceptions and how they combine in the Earth-Sun system. These are not easily understood as evidenced by the large amount of research into student misconceptions, from middle school all the way through college. By far the most common misconception relates the seasons to the distance of the Earth from the Sun, either in general terms or distance related to the tilt of the Earth.

The good news is that teachers can enter the classroom with a pretty good idea of what students are thinking and some very specific strategies for improving student understanding.

1. Understand student misconceptions. Preassess students by asking them to write a short paragraph explaining the cause of the seasons or asking the two multiple-choice questions from the Sadler study. Use the results to better understand what students are thinking.

2. Ask students to observe the pattern of the Sun in the sky over a period of several months. Discuss student observations as a class and ask what effect the changing position of the Sun may have on the seasons.

3. Challenge student misconceptions with anomalous data (the Earth is closest to the Sun in January, etc.) and have students defend their positions with explanations and classroom discussion.

4. Use physical models to show how the Earth's axis always points in the same direction as Earth orbits around the Sun and how the shape of the Earth and the tilt impact the intensity of radiant energy from the Sun.

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