The Good, the Bad, and the Ugly: Instructional Materials for the Seasons and Color (Misconceptions, Misleading Diagrams and Terminology, and the Importance of Inquiry)

San Dieguito Middle and High School Teachers In-Service

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www.sci-ed-ga.org (click on presentations)

General Atomics

Presented 1/26/04 at

La Costa Canyon High School

- I want to thank Biology teachers for showing up for a topic that appears to be more earth science, physics, and chemistry.
- I think you will find this useful

5 disclaimers

5. I am not a teacher.
4. I have never taught students.
3. I have no conception of the life of a teacher.
2. I am here as a "science education expert," but I have no formal science education training.
1. "Science is the belief in the ignorance of experts" – Richard Feynman

Why is it hotter in the summer than the winter?

Let’s now watch the video

“A Private Universe”

Why didn't the Harvard folks learn the correct reasons for the seasons?

Why didn't the student learn the correct reasons for the seasons?

- Good teacher
- Good student
- Good/standard demonstration
- Good school
- Rigorous text book

Why didn't the Harvard folks or the student learn the correct reasons for the seasons?

- General point: background experience of students: if you move closer to a hot object, you will get hotter – need to determine students preconceived ideas
- The need to experience why their preconceived ideas might be wrong
- Students need "hands-on" and "minds on" activities, not just being told and seeing demonstrations, to learn
- Students need multiple different activities to learn the correct conceptualization, especially for
  - Complex phenomena
  - Phenomena for which they have no common physical experience
  - Phenomena that are inconsistent with their everyday experiences
- These activities must be designed to dispel their very reasonable existing knowledge and must provide robust learning that will remain in their long-term memory and be able to be applied to new situations

Why didn’t the Harvard folks or the student learn the correct reasons for the seasons?

- The materials must also provide realistic and understandable diagrams so that students have a visual clue to anchor their understanding
- The materials must not use misleading and confusing terminology
- The materials must be scientifically correct.

“The goal of education is meaningful learning” (from A Private Universe Teacher’s Guide

- “Meaningful learning results in understanding that the student can apply to new situations.”
- “In rote learning, the student’s grasp of the subject is limited to classroom contexts and is often of short duration.”
- “Students who are proficient at rote memorization often get the right answer on standard exams without really comprehending the fundamental ideas behind the answer.”

A Private Universe video
Harvard students explaining the seasons
www.learner.org/resources/series28.html

Minds of Their Own video
MIT students making simple circuits
www.learner.org/resources/series26.html

"A Private Universe" Resources

- General Information
  - http://www.learner.org/channel/workshops/privuniv/intro.html
- Using "A Private Universe" video with high school students:
  - http://www.learner.org/teacherslab/pup/usinghs.html
- Private Universe activities
  - http://www.learner.org/teacherslab/pup/
- Broadcast dates
  - http://www.learner.org/channel/series29.html
- Modeling workshops to learning how to teach inquiry in high school
  - http://modeling.asu.edu

Few Teachers Publicly Admit That Their Teaching was Ineffective

"My present concern with undergraduate science education began in the early fall of 1980 when, being assigned by happenstance to teach a physics class for perspective elementary teachers, I gave the first examination. The results showed quite clearly that my brilliant lectures and exciting demonstrations on Newtonian mechanics had passed through the students' minds leaving no measurable trace."

"Seeking advice on efficacious physics pedagogy for future elementary teachers, I telephoned around the country with little success until the late Robert Karplus at Berkeley advised me to call "the only person in the country who understands the problem," Arnold Arons at the University of Washington. In a watershed 30-minute telephone conversation, Arons, speaking from 12 years of hard-won experience with elementary education majors (Arons, 1977), recommended that *I abandon the standard passive student lecture*. He patiently explained his physics education method: hands-on laboratory experience with concrete physical systems, repeated interactive engagement at increasingly sophisticated levels, emphasis on operational definitions, and Socratic dialogue."

Richard Hake, Emeritus Professor of Physics, Indiana University

http://www.physics.indiana.edu/~hake

Interactive engagement vs traditional instruction

- (a) "Interactive Engagement" (IE) methods are *designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors*
- (b) "Traditional" (T) courses are those reported by instructors to *rely primarily on passive-student lectures, recipe labs, and algorithmic problem exams*

Richard Hake, Emeritus Professor of Physics, Indiana University

Scientific evidence: interactive engagement is more effective than passive lecture

III. CONCEPTUAL TEST RESULTS

A. Gain vs Pretest Graph - All Data

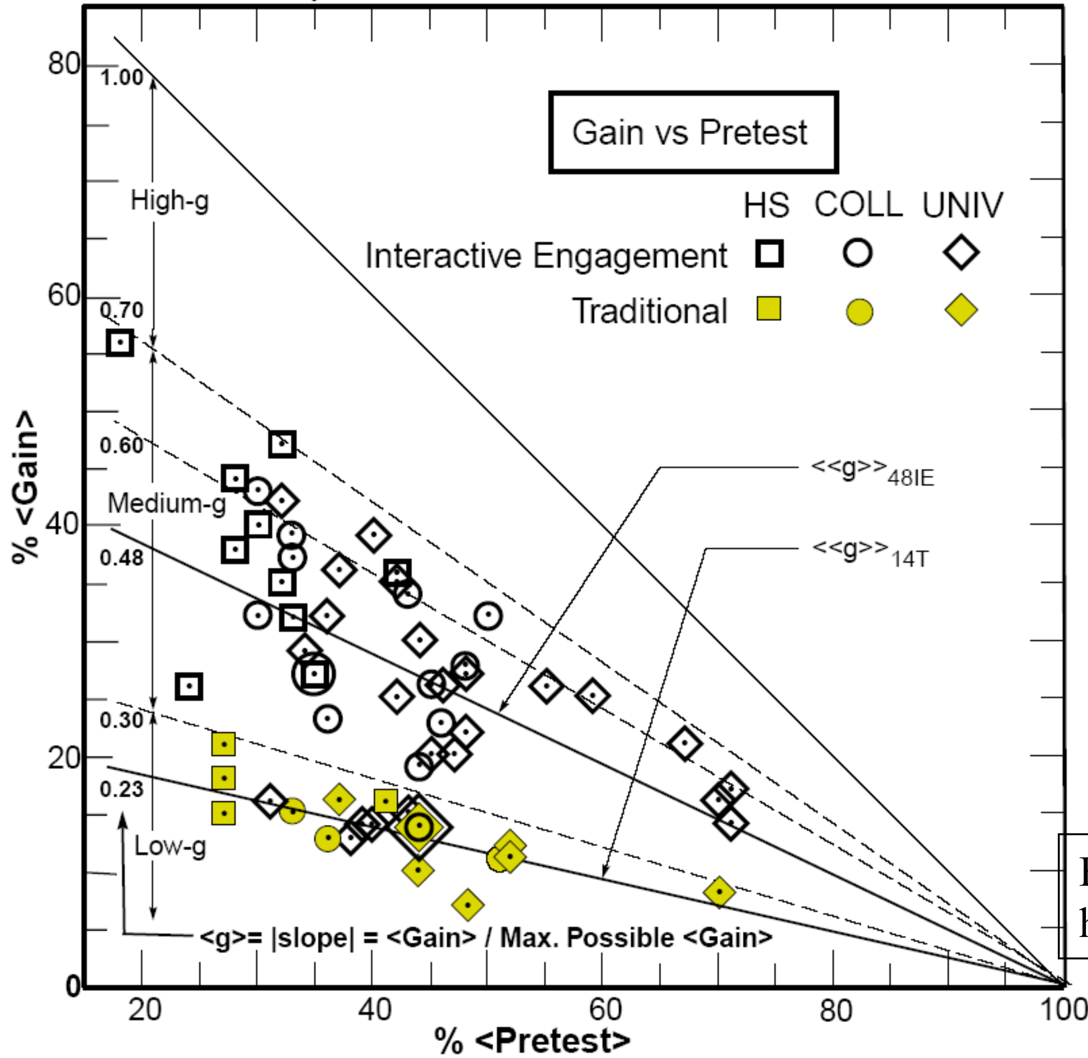


Fig. 1. %<Gain> vs %<Pretest> score on the conceptual Mechanics Diagnostic (MD) or Force Concept Inventory (FCI) tests for 62 courses enrolling a total N = 6542 students: 14 traditional (T) courses (N = 2084) which made little or no use of interactive engagement (IE) methods, and 48 IE courses (N = 4458) which made considerable use of IE methods. Slope lines for the average of the 14 T courses $\langle\langle g\rangle\rangle_{14T}$ and 48 IE courses $\langle\langle g\rangle\rangle_{48IE}$ are shown, as explained in the text.

"Interactive-engagement vs traditional methods: A six-thousand student survey of mechanics test data for introductory physicscourses"

Richard R. Hake

Department of Physics, Indiana University, Bloomington, Indiana 47405

From: http://www.physics.indiana.edu/~hake/

CA state education policy will soon effectively end hands-on activities in K-8

- **Criteria for Evaluating K-8 Science Instructional Materials <http://www.cde.ca.gov/cfir/science/>**
- "A table of evidence in the teacher edition, demonstrating that the California Science Standards can be comprehensively taught from the submitted materials with hands-on activities composing no more than 20 to 25 percent of science instructional time (as specified in the California Science Framework)."

But this ruling is being fought by many scientists and educators:

<http://lists.psu.edu/cgi-bin/wa?A2=ind0401&L=physhare&O=D&P=10483>

…This 25% limitation is at odds with curricula and programs advocated by the National Science Education Standards, the American Association for the Advancement of Science, the American Association of Physics Teachers, the American Physical Society, the American Chemical Society, the National Association of Biology Teachers, the National Science Foundation, and the National Science Teachers Association. These organizations represent hundreds of thousands of scientists and science educators. None of these organizations have proposed or supported the limitation of hands-on activities as proposed by the draft Criteria…

…Who is in favor of the 20-25% limitation? The handful of writers of this Criteria and the relevant section of the Framework. This handful of people must have strong evidence that hands-on programs in excess of 25% are detrimental to science learning. But do they? Where is their evidence?…

…As far as I know, it is non-existent. It is contrary to the views of thousands of scientists and science educators. It is also contrary to over 30 years of education research…

Dr. Lawrence Woolf testimony to the California Curriculum Development and Supplemental Materials Commission on 1/16/04 in Sacramento CA

Dinosaur in a Haystack by Stephen Jay Gould (p.249)

"… a favorite theme of these essays and an important principle in the history of science" the central role of pictures, graphs, and other forms of visual representation in channeling and constraining our thought. Intellectual innovation often requires, above all else, a new image to embody a novel theory. Primates are visual animals, and we think best in pictorial or geometric terms. Words are an evolutionary afterthought."

*"Be very, very careful what you put into that head,
because you will never, ever get it out."*

Thomas Cardinal Wolsey (1471-1530)

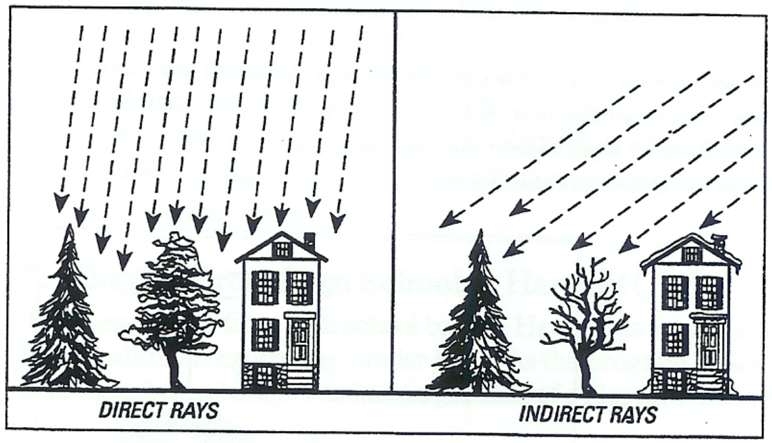
From the Bad Science web site:
<http://www.ems.psu.edu/~fraser/BadScience.html>)

Even the Teacher’s Guide and web site associated with “A Private Universe” contributes to misconceptions about the seasons!

Misleading use of terms contributes to misconceptions

- Direct: Proceeding in a straight line or by the shortest course; straight; undeviating; not oblique
- Indirect: Not direct in space; deviating from a straight line
  - Indirect lighting: reflected or diffused light; lighting in which the light emitted by a source is diffusely reflected (as by the ceiling)
- Weak: Lacking physical strength, energy, or vigor; feeble.
- Strong: Physically powerful; capable of exerting great physical force.

Note the use of the misleading terms "indirect rays" and "direct rays." The last line also suggests that Earth's surface only cools off at night, rather than all of the time.



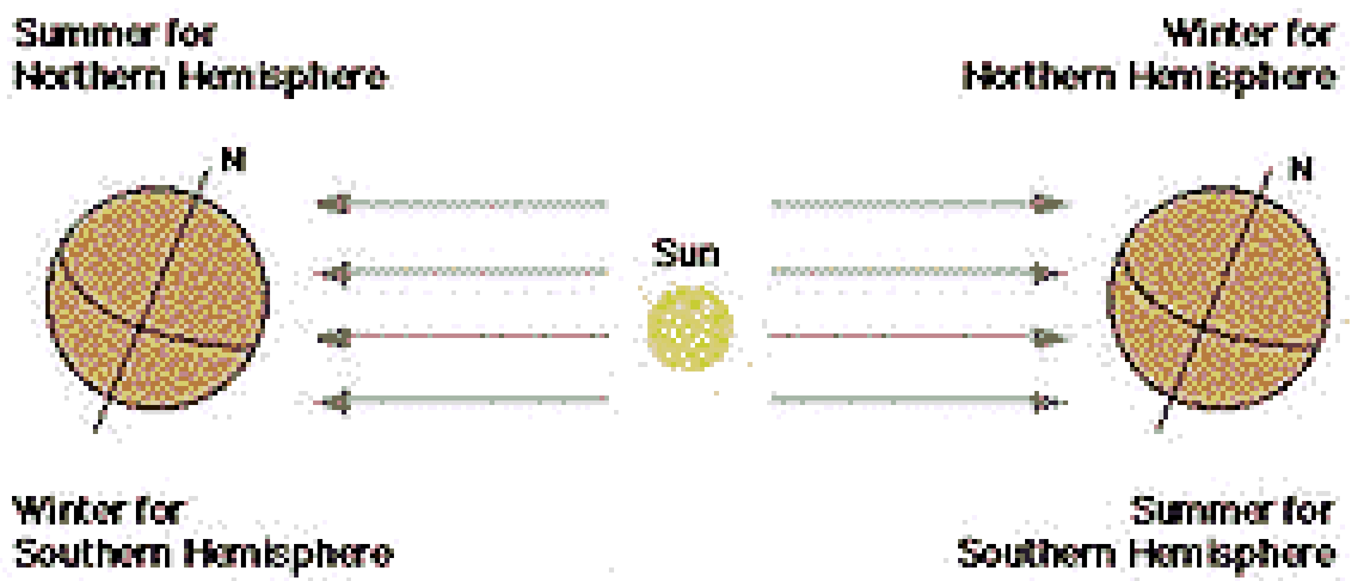
Two factors resulting from the tilt of the Earth's axis account for seasonal weather changes. First, in summer the Sun shines higher in the sky and its rays beat more directly down, warming the surfaces they contact. In the winter when the Sun is lower in the sky, its light reaches the ground at a lower angle, spreading out its warming ability. This is the phenomenon sometimes referred to as "indirect rays."

Variations in the Length of Daylight

The second factor contributing to the seasons is the length of the daylight period. Because of the tilt of the Earth's axis, daylight lasts longer in the summer than in the winter. The farther you travel from the equator, the more extreme this contrast becomes. So not only is the Sun's warming light less effective in the winter but there are fewer hours of it. Also, the Earth's surface has more time to cool off at night in winter than in summer.

From: A Private Universe Teacher's Guide, p. 18

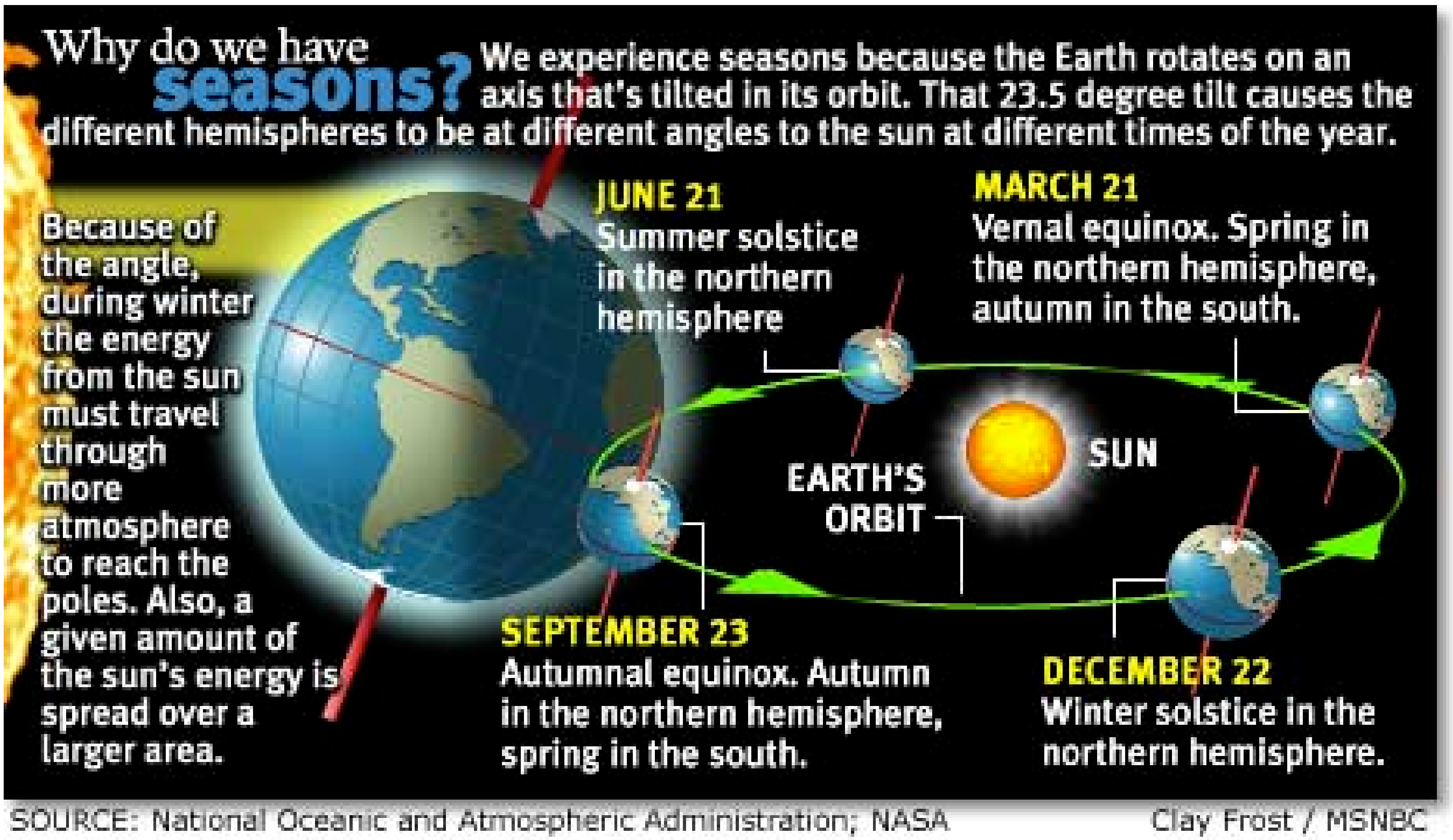
Even though the text states that the figure is not to scale, the image is still misleading. Also note that the sun is shown emitting rays in two opposite directions from the Sun.



‘The seasons are caused by the simple fact that the Earth's axis of rotation is not perpendicular to the plane of its orbit. Rather, the Earth's axis is tilted some 23°.5 away from the perpendicular, as shown in the figure (which is NOT to scale).”

http://hea-www.harvard.edu/ECT/the_book/Chap2/Chapter2.html

According to MSNBC, NOAA, and NASA, the amount of atmosphere the sun passes through is the main cause of the seasons -is this true?
Also note the incorrect scale of the drawing with no notation that it is not to scale.



From: http://www.msnbc.com/news/251727.asp

According to MSNBC text, a main reason for seasons is the energy absorbing atmosphere. Note also the use of misleading terms “weak” and “strong” rays.

“Around the time of the June solstice, the North Pole is tilted toward the sun and the Northern Hemisphere is starting to enjoy summer. The **sun’s rays are strong** because they are directly overhead. They are concentrated over a smaller surface area and **travel through a relatively small amount of energy-absorbing atmosphere** before striking the earth.”

”At the same time that the Northern Hemisphere is entering summer, the South Pole is tilted away from the sun, and the Southern Hemisphere is starting to feel the cold of winter. The **sun’s rays are weak** because they are spread over a greater surface area and must **travel through more energy-absorbing atmosphere** to before reaching the earth.”

From: http://www.msnbc.com/news/251727.asp

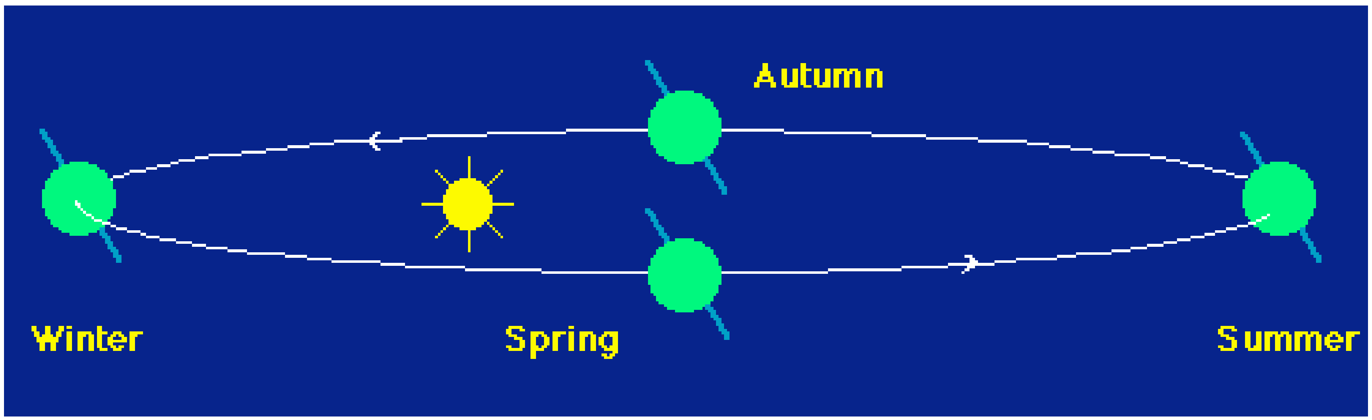
From National Geographic

http://www.nationalgeographic.com/xpeditions/activities/07/season.html

"Because the direction of the Earth's tilt changes in relation to the sun, the northern and southern halves of our planet get differing amounts of sunlight over the course of the year. When the Northern Hemisphere of the Earth is leaning toward the sun, it receives **direct** rays of sunlight and is warmer, while the Southern Hemisphere receives more **indirect** rays."

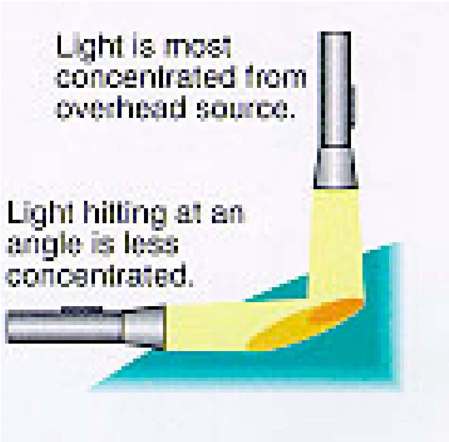
"When the northern part of the Earth is leaning away from the sun, the situation is reversed—the Northern Hemisphere gets **cooler**, more **indirect** sunlight while the southern half receives **direct** rays. Because of this, the seasons in the Northern and Southern Hemispheres are reversed, about six months apart from each other."

To emphasize that the Earth-Sun distance is (very slightly) smaller in the winter than the summer, this figure is overly distorted and misleading



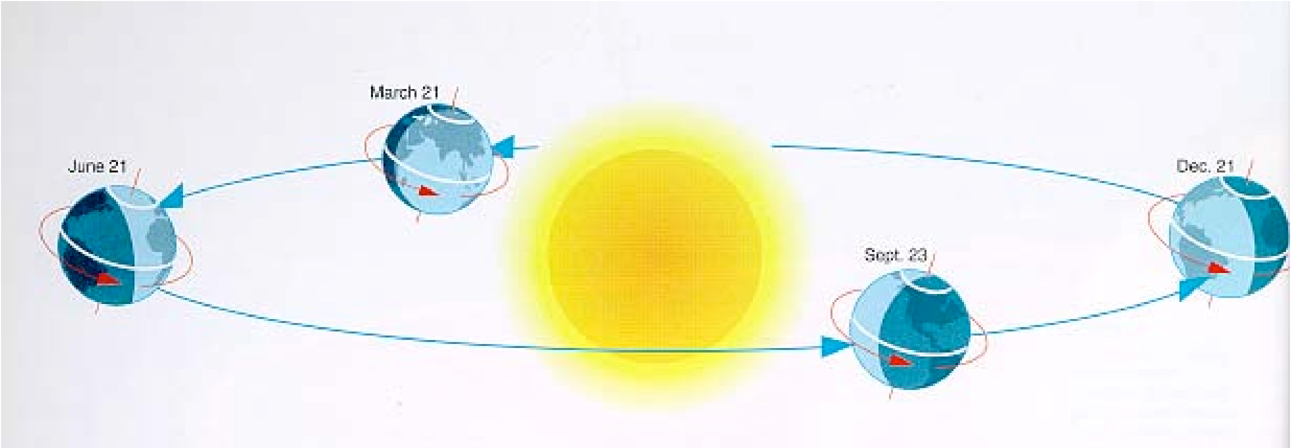
"In fact, as the diagram indicates, the Earth is actually *closer* to the Sun in the N. Hemisphere Winter than in the Summer (as usual, we greatly exaggerate the eccentricity of the elliptical orbit in this diagram)."

http://csep10.phys.utk.edu/astr161/lect/time/seasons.html by Jon Kahl (figures from Jack William's *The USA Today Weather Book*)



Note that the "overhead" source should really be perpendicular to the surface, which it is not.

Note the misleading scale of the Earth-Sun diagram.



http://www.uwm.edu/~kahl/CoVis/Seasons/

From: Earth Science Seventh Edition by Tarbuck and Lutgens

Used in SDUHSD

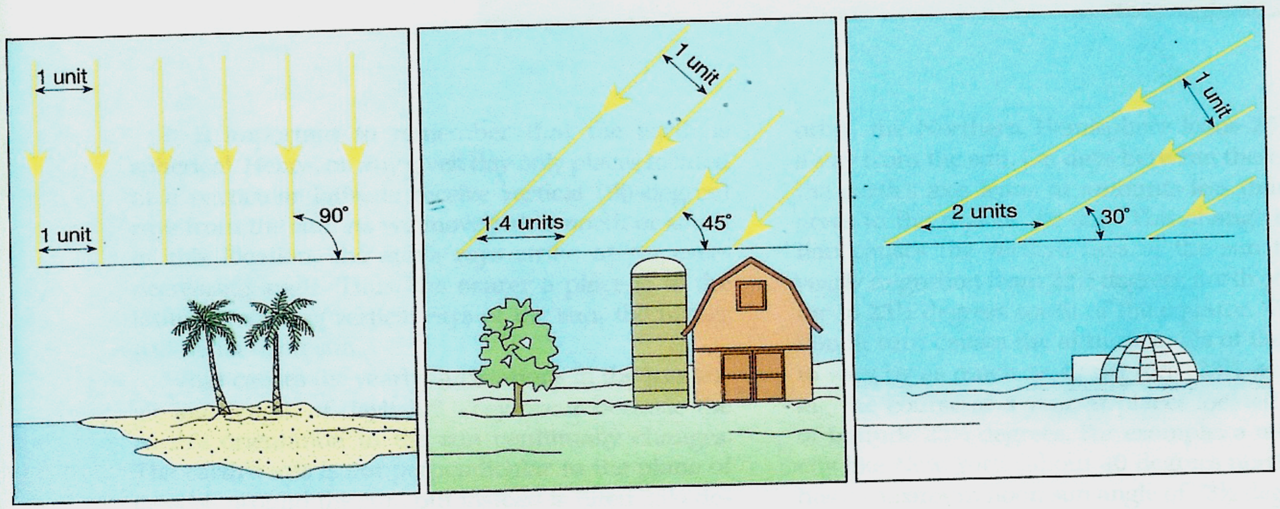


Figure 12.10
Changes in the sun angle cause variations in the amount of solar energy reaching the earth's surface. The higher the angle, the more intense the solar radiation. Notice that one unit of solar energy striking at a 30° angle spreads over twice as much area as that striking at a 90° angle.

Note that this diagram does not provide the perspective of solar energy striking the entire Earth, nor does it show how the density of solar energy varies from winter to summer. The visual image is almost useless.

From: Earth Science Seventh Edition by Tarbuck and Lutgens

Used in SDUHSD

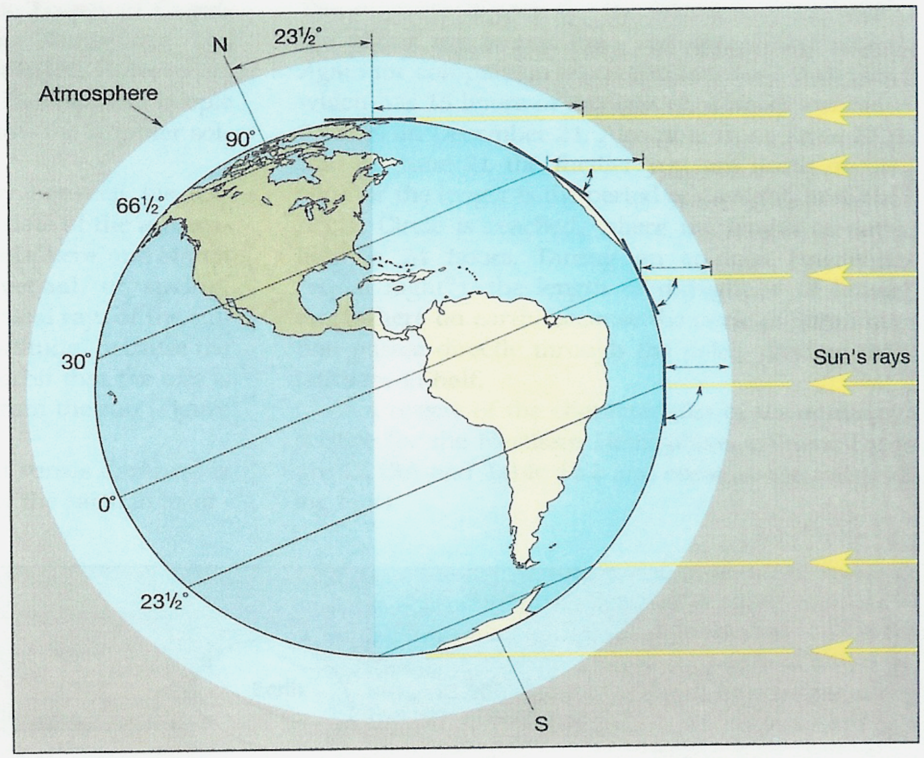


Figure 12.11 *Rays striking at a low angle must travel through more of the atmosphere than rays striking at a higher angle and thus are subject to greater depletion by reflection and absorption.*

This diagram mistakenly leaves the impression that the amount of atmosphere the solar rays pass through is a major contributor to the seasons

From: Earth Science Seventh Edition by Tarbuck and Lutgens

Used by SDUHSD

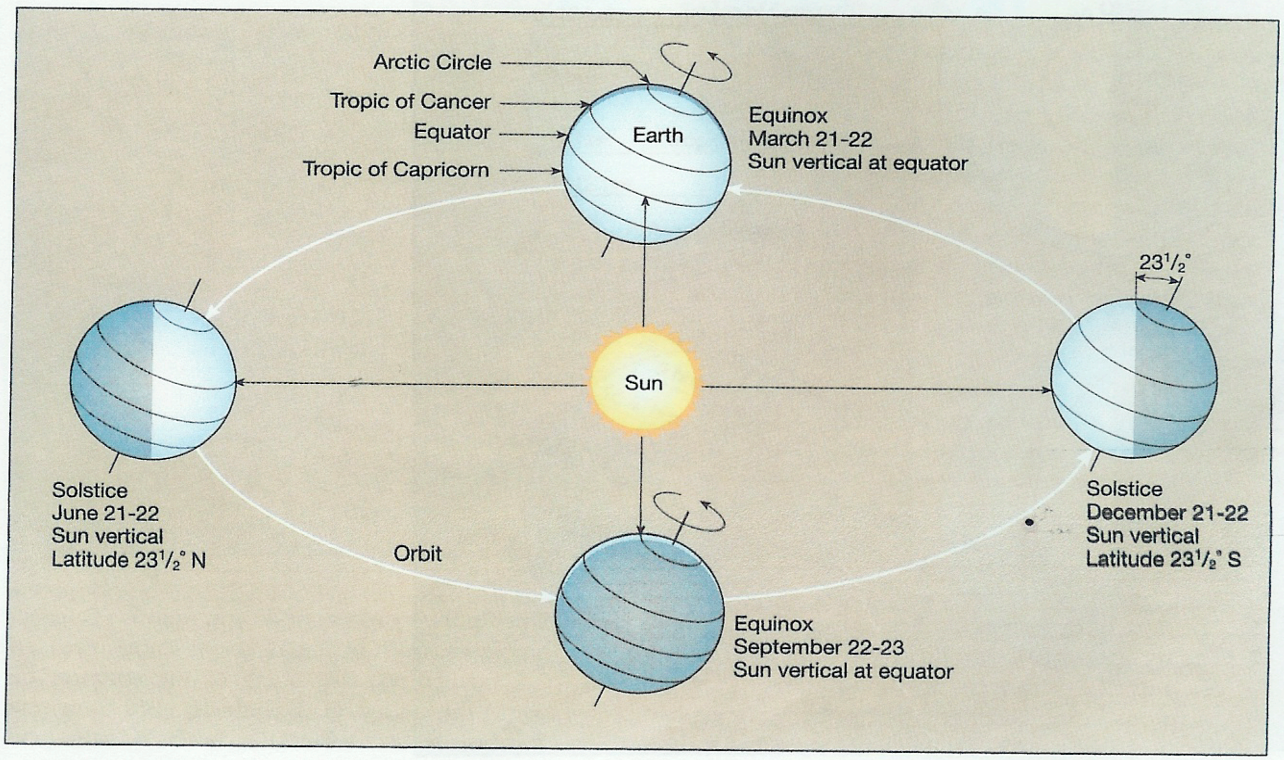


Figure 12.12
Earth-sun relationships.

This diagram is not to scale by a few order of magnitude, yet no mention is made that it is not to scale. This is not the image that students should carry with them.

Bully for Brontosaurus by Stephen Jay Gould (p. 166)

"I can only conclude that someone once wrote the material this way for a reason lost in the mists of time, and that authors of textbooks have been dutifully copying … ever since.

… evidence indicates that cloning bears a discouraging message. It is an easy way out, a substitute for thinking and striving to improve."

Sun-Earth Scale Model

- The standard approach is difficult to visualize and conceptualize (from GEMS: The Real Reasons for Seasons p. 46)
  - Earth: 0.25 cm dia
  - Sun: 28 cm dia
  - Earth-Sun distance: 30 meters !!!
- Better to use a model that can be visualized and used to understand physical situations such as seasons and eclipses"
  - Earth 8000 mi dia --- ~ 10,000 mi = 10^4 mi
  - Sun 865,000 mi dia --- ~1,000,000 mi = 10^6 mi
  - Earth-Sun distance 93,000,000 mi --- ~100,000,000 mi = 10^8 mi
  - So: Sun dia: Earth dia = 100:1
  - And Earth-Sun distance:Sun dia = 100:1
- So if we make the Earth a very small but visible dot:
  - Earth dia = 0.1 mm
  - Sun dia = 10 mm
  - Earth-Sun distance = 1000 mm = 1 m
  - This scale is useable and can be visualized! – see poster

Scale Models

- Appropriate scale models are useful for understanding science
- Can your students construct scale models?
  - Requires proportional reasoning skills:
  - The ability to use algebra to convert units
- Construction of scale model is an extremely useful activity

What are students taught about the rays from the Sun?

- When studying the seasons, the rays are perfectly parallel.
- When studying solar and lunar eclipses, the rays are not parallel at all, but are highly angled.
- Students are taught completely contradictory views, each with no justification.
- This is science by authority, following the “forms of science,” not real science. Science involves “what do we know and how do we know it.”
- (See Cargo Cult Science by Richard Feynman)

<http://www.physics.brocku.ca/etc/cargo_cult_science.html>

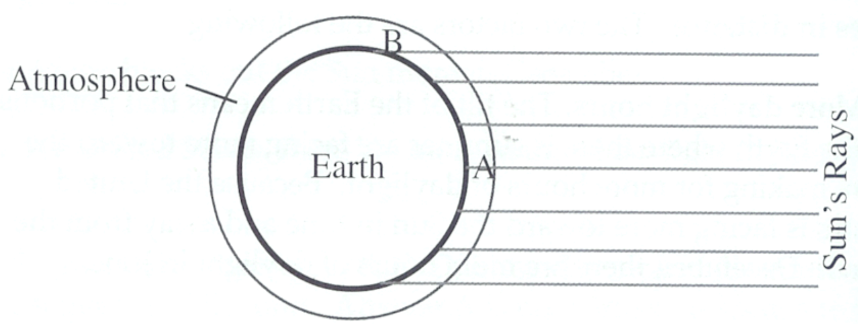
From GEMS: The Real Reasons for Seasons p. 92

Note: Parallel rays from the sun (which is never justified)

Note: States that amount of atmosphere that the sunlight passes through is a minor effect in causing the seasons (but according to MSNBC source, it is the major effect).

What about the effect of the Earth's atmosphere?

Yet another factor related to the Sun's angle and the concentration of light has to do with how much atmosphere the sunlight has to pass through before striking the ground. Light scatters as it goes through the air, so at low Sun angles (point B) light is less concentrated, not only because it spreads out more, but also because less of it reaches the ground. However, this effect is minor compared with the other causes of seasons already discussed.



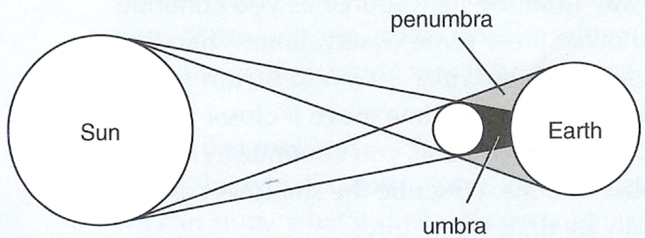
Sun's rays are parallel

From: "What is Light and How Do We Explain It" by Bill G. Aldridge; Scope Sequence and Coordination High School Project of NSTA, 1996

Sun's rays are not parallel

shadows?

When there is a total eclipse of the sun by the moon, the shadow passing over Earth has an area of fuzzy shadow given the Latin name *penumbra* (partial shadow) and an area of dark shadow given the name *umbra* (shadow).



This is a good example of how learning the names tells you nothing about the underlying science, in this case how such shadows are formed. But you now can explain the difference between an umbra and a penumbra and how each is produced. You should, in the same way, be able to explain the difference between an extended light source and a point source of

instead of using a rectangular slit we use a small round hole, we can form a much smaller beam. But if we make the hole too small, there is not enough light to see anything. Do we still have a light beam, small though it may be?

Activity 3: Modeling Light Rays

You can see something resembling a light ray by looking at the light produced by a laser pen as it passes through incense smoke or dust. Set up a glass-walled or clear-plastic-walled fish tank and place incense sticks or a smoke-making device at the bottom of the tank. Create smoke. Then shine the laser light into the tank. Notice that the beam is very narrow. It does, however, have a width so we cannot really call it a *light ray*. ■

Light ray or *ray of light* is another of those science terms whose definition young people often memorize but do not understand. There is no real light ray! A ray of light is like a geometrical line. We can draw lines on paper, but they all have width. If

Is the amount of atmosphere that sunlight passes through a significant factor contributing to the seasons?

- Yes, according to MSNBC/NASA
- No, according to GEMS/NASA
- It is of lesser importance according to the Earth Science – Seventh Edition by Tarbuck and Lutgens
- What is the answer?
  - Theory: This has apparently never been calculated – but it will be soon due email conversations between Craig Bohren and me. "I am going to write my co-author on the atmospheric radiation book, Eugene Clothiaux, and ask him if he can prepare a curve of total optical thickness (scattering and absorption) over the solar spectrum from 0.25 to 2.5 microns for a standard atmosphere." [There is publishable work even in simple middle school textbook issues!]
  - Data: My poster calculation (which can be done by your students for any city in the world) indicates that yearly variation in solar insolation can be understood by considering only variations solar intensity due to angle of sunlight (sine of maximum Sun altitude) and number of daylight hours. These data and calculations indicate that atmospheric effects are relatively unimportant.

Learning about the seasons

- Some students learn that the seasons are due to Earth's tilt, which will allow them to pass a standardized test
- Asking them why the tilt produces seasons tends to produce blank stares.
- What are the big ideas that are the basis for how students should understand the seasons? (Note: there is no right answer - what do you think?)

Learning about the seasons

What are the big ideas that are the basis for how students should understand the seasons?

- Hot objects emit radiation
  - Sun 6000K, much radiation in the visible
  - Earth 300K, all radiation is in the infrared
- Energy conservation
  - Earth absorbs solar energy and emits infrared energy. The energy balance results in a net temperature of Earth.

Learning about the seasons

What are the big ideas that are the basis for how students should understand the seasons?

- Geometry of radiation emitters and absorbers must be considered
  - Earth is far from the Sun (large source) so rays are nearly parallel
  - Earth's axis is tilted resulting in varying amounts of solar energy density and daylight hours
    - The reduced solar intensity with decreasing Sun altitude has many applications
      - The painting of a house with a non-flat surface will take more paint than a flat surface
      - The application of an anti reflection coating on a curved lens surface will take more coating materials than the coating on a flat surface
      - If a coating source is at an angle to a substrate, it will take longer to coat the substrate than if the substrate were perpendicular to the substrate
      - Buying a solar heating or electric system

Let’s look at the Seasons poster

Standards

- California Science Framework (p. 267)
  - "Earth's axis is tilted with respect to the plane of the orbit around the Sun. As a result, different amounts of solar energy reach the two hemispheres at different times, thus causing the seasons."
- National Science Education Standards (grades 5-8), Earth in the Solar System
  - "Seasons result from variations in the amount of solar energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day."
  - As written: solar energy variation due to:
    - Tilt
    - Length of day (length of day is due to tilt)
  - The wording could be improved: the tilt causes:
    - Variation in density of solar radiation (W/cm^2)
    - Changes in length of day

Misconceptions

- Nice discussion at:

http://www.enc.org/features/focus/archive/misconceptions/

- Selections from: How People Learn (http://books.nap.edu/html/howpeople1/)

- The Design of Learning Environments (p. 127)
- Traditional curricula often fail to help students "learn their way around" a discipline. It is the network, the connections among objectives, that is important. This is the kind of knowledge that characterizes expertise.

Selection from: How People Learn (http://books.nap.edu/html/howpeople1/)

"An alternative to simply progressing through a series of exercises that derive from a scope and sequence chart is to expose students to the major features of a subject domain as they arise naturally in problem situations. Activities can be structured so that students are able to explore, explain, extend, and evaluate their progress. Ideas are best introduced when students see a need or a reason for their use--this helps them see relevant uses of knowledge to make sense of what they are learning. Problem situations used to engage students may include the historic reasons for the development of the domain, the relationship of that domain to other domains, or the uses of ideas in that domain"

- Selections from: How People Learn (http://books.nap.edu/html/howpeople1/)

- Transfer of Learning (p. xiii-xiv)
- Skills and knowledge must be extended beyond the narrow contexts in which they are initially learned.
- Learning must be guided by generalized principles in order to be widely applicable. Knowledge learned at the level of rote memory rarely transfers; transfer most likely occurs when the learner knows and understands underlying principles that can be applied to problems in new contexts.

•Selections from: How People Learn (http://books.nap.edu/html/howpeople1/)

•How Experts Differ From Novices (p. 37)

•Knowledge must be "conditionalized" in order to be retrieved when it is needed; otherwise, it remains inert (Whitehead, 1929). Many designs for curriculum instruction and assessment practices fail to emphasize the importance of conditionalized knowledge. For example, texts often present facts and formulas with little attention to helping students learn the conditions under which they are most useful. Many assessments measure only factual knowledge and never ask whether students know when, where, and why to use that knowledge.

Misc. topic #1 –The Importance of Writing Across the Curriculum

- Because I never wrote or talked about science in my science classes, I never really learned the topic well. In industry, you are always writing or talking about your work – proposals, reports, presentations, etc.
- Writing improves your conceptual understanding of science. Example: instead of having students solve a physics problem, have them write about why they are using the equation and how to they are solving the problem
- If you have to talk or write about science, you can't just aimlessly make diagrams or write down equations
- The district lacks formal writing programs using books such as The Elements of Style or The Write Way

Misc. topic #2 –The Importance of Reading Across the Curriculum

- There are excellent popular science books.
- These books provide insight and excitement that textbooks do not provide. Students should be made aware that quality, interesting, informative non-fiction exists. Non-fiction books are rarely read in school. I learned more about optics from Craig Bohren's Clouds in a Glass of Beer than my undergraduate Optics textbook.
- Suggestion: Have your students read a non-fiction science book or chapter or essay and write a report or give a presentation about it – for both English and Science class
- I recently found "A Short History of Nearly Everything" by Bill Bryson fascinating – encompassing physics, chemistry, astronomy, biology, and geology.