

BUILDING TEACHER UNDERSTANDING OF SEASONS AND SEASONAL THERMAL ENERGY BALANCE. M. L. Urquhart^{1,2}, ¹Department of Science/Mathematics Education in the School of Natural Sciences and Mathematics, The University of Texas at Dallas, 800 West Campbell Rd, FN 33, Richardson, TX, 75080, urquhart@utdallas.edu, ²Department of Physics, The University of Texas at Dallas.

Introduction: The reason for seasons is well known in the Astronomy Education Research community as a challenging topic for students and teachers [1]. In my work with in-service and pre-service teachers in an astronomy course in a Master of Arts in Teaching (MAT) program in Science Education [2,3] and in the Texas Regional Collaborative for Excellence in Science Teaching [4,5] at the University of Texas at Dallas (UTD TRC), I utilize a combination of well-known educational resources, assessments, and other activities to build teacher understanding of the seasons.

Here I describe the challenges, activities and assessments utilized, and outcomes of the teacher professional development I conduct on the related topics of seasons and energy balance in a planetary context. I also provide detail on *The Energy Balance Game*, an activity I developed to assist teachers in understanding energy balance in the context of thermal energy absorption, radiation to space, and thermal lag as relates to seasons and diurnal cycles and to climate change.

Experts and Novices: To a space scientist with expert knowledge, the idea that understanding the reason for the seasons represents a conceptual challenge for students may be surprising. In the 1989 video *A Private Universe* [6], “regardless of their science education, 21 of the 23 randomly selected students, faculty, and alumni of Harvard University revealed misconceptions when asked to explain either the seasons or the phases of the moon.” A 1996 study of 49 preservice teachers found that only one had developed a scientific understanding of the topic of seasons [7]. The most common alternate explanation cited the research literature is that Earth-Sun distance is the primary cause for seasons [1]. As with the interviewees in *A Private Universe*, many of my own teacher-participants have the naïve conception that Earth’s orbit is highly elliptical. Many teachers will, however, also assert the seemingly correct response that the tilt of the Earth is responsible for the seasons. However when queried further, the common explanation is that the tilt of the Earth brings one hemisphere closer to the Sun, thus resulting in seasonal differences between the hemispheres. This explanation also was the second most common seen in the 1996 study of preservice teachers [7]. Further, Atwood and Atwood go on to say “a large percentage of the sample had declarative knowledge that the earth is tilted on its axis. Unfortunately,

that knowledge did not prove to be functional for showing and explaining the causes of seasons.” [7] For a novice, mental models need be neither complete nor self-consistent to be firmly held and resistant to change. Compounding this issue is that in the state of Texas [8], as well as elsewhere, astronomy topics such as seasons are taught primarily by elementary and middle school teachers who typically have little to no astronomy background.

Guiding Conceptual Change: Several strategies are used to identify naïve conceptions in the teachers with whom I work and to guide conceptual change. Prior to any instruction, I use pre-testing on concepts related to seasons with my own instrument and the *Astronomy Diagnostic Test* [9]. The teachers and I begin our exploration of seasons by watching and discussing the video *A Private Universe* [6] to encourage metacognition among teacher participants in the context of student learning. We then go through several activities in *The Real Reason for the Seasons* guide from the Lawrence Hall of Science Great Explorations in Math and Science (GEMS) series [10].

Produced in partnership with NASA in 2000, *The Real Reason for the Seasons* builds on the findings of the Astronomy Education Research community. Although designed for students in grades 6-8, I have found the activities in this guide to be valuable for adult learners. Topics addressed include: the nearly circular shape of the Earth’s orbit and nearly constant angular size of the Sun; concentration of solar energy as a function of incidence angle; variation in hours of daylight by latitude; and variations in annual and diurnal temperature at different latitudes.

Segments showing seasonal progression by latitude from the BBC/Discovery Channel video *Pole to Pole* in the *Planet Earth* [11] series provide a global overview of seasons. NASA spacecraft imagery of illumination of the Earth and other planetary bodies is used to strengthen the concept of tilt as related to hours of illumination and solar incidence angle. Online interactives, such as those from the Nebraska Astronomy Applet Project [12], assist participants in exploring sunrise, sunset, angle of the sky, and hours of daylight throughout the year at different latitudes.

Discussions throughout and open-ended journaling prompts allow for a diagnosis of conceptual change. The activities described above are often successful

based on outcomes measured by assessments. However, post-instruction some participants still maintain that the tilt of the Earth causes seasons by bringing one hemisphere closer to the Sun and the tilting the other farther away. The most effective strategy I have found for combating this particular misconception is to return to the Scale Model Solar System [13]. On a 1 to 10 billion scale, the Earth can be modeled by a ~1.3 cm diameter candy sprinkle, and the Sun by a 14 cm ball. The scaled Earth-Sun distance is 15 m. Standing in one corner of a classroom, with a student holding the model Sun in the opposite corner at ~15 m away, I remind participants of the model and then tilt a candy sprinkle held between my fingers. I ask “Does tilting the model Earth bring it meaningfully closer to the model Sun?”

During the course of my unit on seasons, I also introduce tracking of times of local sunrise, sunset, and shadow lengths as a method to encourage the development of student understanding of the importance of both length of number of daylight hours and sun angle to seasonal changes. Questions often arise during this discussion, and in the course of the other activities, such as: 1) Why isn’t summer solstice the hottest day of the year? 2) Why isn’t winter solstice usually the coldest day of the year? 3) Why do the seasons begin at equinox and solstice? Addressing these questions, connecting to other astronomy and planetary science topics, and my own experience as a thermal modeler, led to the development of *The Energy Balance Game*.

The Energy Balance Game: In this activity, participants work in groups to model energy flow from the Sun, to the Earth, and out to space. Physical objects such as gram cubes, coins, or beads represent “energy units” and are moved between three cups, labeled “Sun”, “Earth”, and “Space” to model solar energy absorption and the Earth’s thermal infrared radiation. The more energy units remaining in the Earth cup for each month, the higher the average temperature.

Students begin by completing a table that assumes varying energy input and constant energy output (temperature independent model) for each month of the year at a single location in the northern hemisphere. Moving the physical objects representing energy units from the Sun cup, to the Earth cup, and then to the space cup, participants tally the number of energy units remaining in the Earth cup at the end of each month. Physically moving objects has proved valuable. More advanced participants who try to quickly calculate the remaining energy units often have to go back and make corrections, delaying completion in comparison with participants who use the manipulatives as intended.

Following questions intended to spur conversation and thought among small groups of participants, the temperature dependent model is completed. The iden-

tical inputs of energy units from the Sun over the course of the year are used from the prior model, with a varying number of energy units radiated to space. More units are moved to the space when more energy units have accumulated in the Earth cup (ie, at higher temperatures), and fewer when less have accumulated. This model produces a more realistic average monthly temperature, with the most energy units accumulating in midsummer and the least in midwinter.

As with all models, there are limitations to the activity. For example, the Earth cup begins and ends empty over the course of a year to simplify tallying, with the empty cup representing a minimum thermal energy and temperature. A small number of total objects representing energy units (50) are used to model energy balance over the course of a year rather than realistic values based on insolation and the Stefan-Boltzman law. Average monthly temperature also depends on many factors, and therefore the tables may need to be adjusted to fit a particular location.

Following creation of their data tables, groups of participants are asked to consider how the model could be adjusted for their own location, and for countries near the equator and in the southern hemisphere. Climate change is introduced with a discussion of what would happen to the temperature of the Earth if one extra energy unit accumulates or is lost each year. Participants are then asked to consider processes that could lead to a net change over the course of a year.

Conclusions: Building understanding of the causes and complexities of the seasons is challenging. No single approach or resource is the sole solution. Many excellent resources are available. However, limiting factors in my choices of instructional activities are the expense, availability, and appropriateness for teachers to use in their own classrooms. *The Energy Balance Game* described here is available to teachers and others at no-cost for credited non-profit use and modification.

References: [1] Bailey J. M. and Slater T. F. (2003) *Astro. Ed. Res.*, 2, 20–45. [2] Urquhart M. L. and Montgomery H. A. (2012) *LPS XLIII*, Abstract #1659. [3] Urquhart M. L. (2015) *LPS XLVI*, Abstract #1832. [4] <http://www.utdallas.edu/scimathed/> [5] <http://thetrc.org> [6] Schneps, M. H. and Sadler P. M. (1989) *A Private Universe* [Video]. [7] Atwood R. K. and Atwood V. A. (1996) *J. Res. in Sci. Teach* 33, 553–563. [8] Texas Essential Knowledge and Skills in Science <http://ritter.tea.state.tx.us/rules/tac/chapter112/> [9] Hefnagel B. and the CAER, *Astro. Ed. Res.*, 1, 47–51. [10] Gould A. et al. (2000) The Real Reason for the Seasons. [11] <http://store.discoveryeducation.com/> [12] <http://astro.unl.edu/naap/> [13] Urquhart, M. L. (2002) *LPS XXXIII*. Abstract #2007.