RESOURCES AND STRATEGIES FOR BUILDING UNDERSTANDING OF THE EARTH–MOON–SUN SYSTEM IN STUDENTS OF ALL AGES. M. L. Urquhart[1,2], [1]Department of Science/Mathematics Education, The University of Texas at Dallas (FN 33, 800 West Campbell Road, Richardson, TX, 75080, urquhart@utdallas.edu), [2]William B. Hanson Center for Space Sciences, The University of Texas at Dallas.

Introduction: Our home planet, its large natural satellite, and our own star: for NASA's Year of the Solar System [1], these the objects in our planetary system are in many respects the easiest for school children and the general public to study. And yet, understanding the Earth-Moon-Sun system presents challenges for learners of all ages. Lunar phases, for example, are well established to be challenging to adult learners. Children as well as adults (students, teachers, and the public) have common naïve conceptions/misconceptions, including the idea that a new moon is caused by Earth's shadow or that the entire phase cycle can be completed in 24 hours [2,3,4,5]. Research indicates that these incorrect ideas are also resistant to change [2]. Educational outreach and professional development programs at The University of Texas at Dallas (UT Dallas) utilize a variety of approaches to assist teachers in developing a level of expertise necessary to guide their own students with this and other topics related to the Earth–Moon–Sun system. We leverage both pre-existing resources and ones created in house, and detail those here. Our general approach is constructivist, and built on learner observations [6]. The mixture of authentic observational science, online data, and modeling strategies recommended varies with the age of the students.

Authentic Science: Observations of the Moon in the sky are an excellent form of authentic science, and can be done with nearly any age group, including primary grade students. Two schools in the Dallas-Fort Worth metropolitan area have 2nd grade students and their teachers observing the Moon for an entire phase cycle. At one of these, Boon Elementary in the suburban Allen Independent School District, 2nd grade students and their families have for the past several years completed daily lunar observations to support a class lunar observing log. The observing plan and associated classroom activities were created in a partnership between the school faculty and UT Dallas. At Dallas's Burnet Elementary, 2nd grade students on the predominately economically disadvantaged campus with a high percentage of English Language Learners use in-school observations of the Moon made with their teacher to complete their own class lunar logs, based on what has been done at Boon Elementary. The entire staff of Burnet Elementary is receiving professional development in a partnership between the school and the UT Dallas, as part of the Texas Regional Collaboratives for Excellence in Science/Mathematics Teaching. [7] The revised Texas state science standards that went into effect in the 2010-2011 school year require that 2nd graders throughout the state "observe, describe, and record patterns of objects in the sky, including the appearance of the Moon." [8] Although 2nd graders are not expected to understand the causes of lunar phases, these early observations of the lunar phase cycle may prevent the formation of many misconceptions associated with the topic that have been demonstrated to be common in adults. We are planning to test this hypothesisin partnership with one or both schools. For older students, observations can serve as the foundation for modeling activities and help address this conceptually challenging topic. Lunar phase logs are an extremely inexpensive way to do authentic science, requiring at minimum no more equipment than a paper and pencil. However, even telescope observations of the lunar surface can be conducted at low cost thanks to innovations such as The Galileoscope™, a small inexpensive telescope produced for the International Year of Astronomy [9].

Solar observations, while easily done at a university, are more difficult to conduct with young children particularly in regards to safety. Yet the reasons for seasons is also a conceptually challenging topic, as highlighted in the film *A Private Universe* [4], as can be that the Sun is also the central object in our solar system as well as a dynamic star. However, in addition to pinhole style viewers or solar telescopes and use of NASA outreach websites such as SOHO [10] and STEREO [11] and applications such as the 3-Sun [12], we have found several simple and inexpensive ways to incorporate solar science observations into professional development, public school, and outreach activities. Tracking sunrise and set times, for example, allow students to make the correlation between length of day, temperature, and season. Likewise, shadow lengths can be measured daily or weekly on a playground or sidewalk at a particular time of day. The GEMS guide *The Real Reasons for Seasons* [13], while targeted at middle school, has been well received by teachers in the UT Dallas Master of Arts (MAT) program in Science Education [14].

While solar telescopes and telescope filters can be costly, solar eclipse viewing glasses/viewers (at less than $1 each) provide an inexpensive alternative for direct observations of sunspots. Tracking sunspots and solar rotation can be done quantitatively or qualitatively with SOHO/STEREO images. For the latter, daily images over a solar rotation can made into a flip-book (archived solar images from solar maximum work well when sunspot numbers are low) or qualitatively with a pinhole viewer or a commercial image projecting telescope such as a Sunspotter™.

From the CINDI E/PO Program: NASA's small Mission of Opportunity, the Coupled Ion Neutral Dynamics Investigation (CINDI), was built at UT Dallas and is currently in an extended mission to study space weather in Earth's ionosphere on the Air Force C/NOFS satellite [15]. Several of the resources/activities used in the CINDI Education/Public Outreach program, for which the author is an E/PO Co-Lead, can be used to help students better understand the Earth/Moon/Sun system, as well as the impact of space weather on our modern high-tech society. The first activity is a scale model of the Earth's atmosphere including common objects such as clouds and commercial airplanes, and low Earth orbiting satellites. The second is a scale model of the Earth-Moon system. Both are as lesson plans with supporting presentation slides available for free download from the CINDI website and are used in our programs to assess and build student understanding of distances within the Earth-Moon system. In turn, scale in the Earth-Moon system has helped teachers within our program understand why eclipses are special events as well as some of the challenges distance can make with regard to space exploration [16]. For example, activity participants, regardless of age, are surprised to learn that the altitude of C/NOFS carrying CINDI (at apogee very close to that of the International Space Station) is a mere 1/1000th of the Earth-Moon distance. Likewise, in astronomy classes at UT Dallas, the author's Scale Model Solar System using a 1 to 10 billion scale in which the Earth is the size of a candy sprinkle and the Sun is the size of a large grapefruit, with a separation of 15 m between them [17], has been essential in combating the misconception that summer is cause by a specific hemisphere of the Earth being tilted closer in distance to the Sun in summer and farther in winter. All of these scale modeling activities further benefit from another CINDI resource developed to help students understand large numbers: *How Big is a Million?* [18]

The Lunar Phase Wheel (LPW) is a unique resource created by the author to help teachers develop expert-level understanding necessary to teach lunar phases in their own classrooms. Tested at UT Dallas since 2005, the resource and accompanying laboratory exercises debuted in a workshop at Cosmos in the Classroom 2010, and will be published in the conference proceedings. The motivation for the LPW came from the Lunar Phases Concept Inventory (LPCI) [19] data obtained from UT Dallas MAT astronomy classes in which despite high overall normalized gains (0.4 - 0.6) students had repeated difficulty with several questions that involved mental manipulation of relative positions of the Earth, Moon, and Sun. The LPW was designed as a scaffolding tool for adult learners to explore the relative appearance of the Moon in the sky, the time period in which a specific phase is visible over a day-night cycle, and the relationship between the position of the Sun and the Moon in the sky during specific lunar phases.

A critical part of the LPW is the third wheel with a single window allowing for only one phase at a time to be viewed. The intent of this window is to limit cognitive load on the user. MAT students at UT Dallas have responded very well to this resource, with pre/post normalized gains ranging from 0.60 to 0.84 (with small n numbers ranging from 6 to 19) and posttest class averages between 86 and 95%. The LPW, as with all resources by the author mentioned here, are available either on the CINDI website or by request.

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