**Using Embedded Assessments in Educational Outreach Activities to Identify and Address Naïve Conceptions of Scale in the Solar System.** M. L. Urquhart, Department of Science/Mathematics Education and Center for Space Sciences, University of Texas at Dallas (Mail Station FN 33, 800 W Campbell Road, Richardson, TX, 75080-3021, urquhart@utdallas.edu).

**Introduction:** Scale models of the solar system are a classic tool in astronomy education. Often, however, these models are pre-made or are constructed by students following instructions that are not inquiry-based. By embedding assessments within scale modeling activities, we can simultaneously access the pre-existing ideas learners bring with them and provide an active learning opportunity for concepts of scale in the solar system. These embedded assessments allow for instruction that is inline with constructivist learning theory [1] and national science education reform efforts [2,3].

**Embedded Assessments:** The education and public outreach (E/PO) activities described here use a common format for identifying and addressing naïve conceptions of scale that are inconsistent with scientifically accurate models:
- The activity facilitator uses a portion of the physical model to introduce the scale factor using a physical model of a portion of the system.
- Participants in the activity are asked to predict relative sizes or distances of objects in the model system.
- Participants are then asked to create an accurate scale model using data on actual and/or scaled sizes/distances given by the facilitator.
- Participants are asked to reflect on their previous ideas following creation of the scale model by comparing their predictions with the model created using data and measurements.
- Participants are asked to apply knowledge to make new predictions with the scale model.

When using embedded assessments in this way, it is important for the facilitator to create a safe learning environment during the activity in which participants may freely express their initial ideas of scale. When working with teachers who may be easily embarrassed by the admission of less than perfect content knowledge on the subject, the facilitator may ask for the participants to give predictions based on what they think will be common student responses to the prediction of size and/or distance scale in the system being modeled.

The E/PO activities described here were designed for formal (classroom-based) education targeted at grades 6-8. However, they are also used extensively in professional development programs for teachers and can be adapted for use in undergraduate astronomy education [4].

**Scale in the Earth-Moon System:** The activities for scale in the Earth-Moon system described here are part of the joint NASA/Air Force Coupled Ion Neutral Dynamics Investigation (CINDI) E/PO program [5] for which the author is an E/PO Co-Lead. Two different models, both based on pre-existing activities [6,7] are used to help activity participants develop an understanding of scale in the Earth-Moon system with an emphasis on applications to space weather and space exploration. The first is a paper model showing the layers of the atmosphere with 100 km/page of standard 8 ½” x 11” paper and the second uses half a standard-size container of play dough divided into 50 equal pieces to create a scale model in size of the Earth-Moon system, which is then used to create a model in distance. The separate and combined models are used as a springboard for discussions of the orbits of satellites, challenges of space exploration, space weather, and more.

*Combining models and changing scale factors:* The atmosphere scale model introduces participants to the distance of the orbiting International Space Station, Space Shuttle, and the future Air Force Communication/Navigation Outage Forecast Outage Satellite (C/NOFS) that will carry the CINDI instrument package. Each of these spacecraft is or will be in low Earth orbit. Once participants have created their Earth-Moon model to scale in both size and distance, they are asked to predict where these spacecraft orbit relative to the Earth and Moon. Most participants greatly overestimate how far satellites orbit from the Earth (~1/1000th of the Earth-Moon distance for the ISS or space shuttle) just as they underestimate the Earth-Moon distance. The atmosphere model can then be revisited through a discussion of how much paper would need to be added to include both the Earth and Moon to scale in size and distance on that model:
- How many sheets of paper are in your model of the Earth’s atmosphere?
- The Moon is about 384,000 km from the Earth. How many sheets of paper would you need to add the Moon to your atmospheric model?
- The Earth has a diameter of 12,756 km. How many sheets of paper would you need to add the size of the Earth to your scale model?
The Moon has a diameter of 3476 km. How many sheets of paper would you need to include the size of the Moon to scale on your model?

**Taking it further.** Once participants have created the Earth-Moon model to scale, it can be used to explore other challenging topics in astronomy, including the difference between a new moon and lunar eclipse and the role of scale in lunar and solar eclipses with an easy-to-use hand-held model.

**Scale in the Solar System and Beyond:** A scale model of Sun and planets can also be made using the same approach. My own version of this classic activity uses the 1:10 billion scale factor of the *Colorado Model Solar System* on the campus of the University of Colorado at Boulder and *Voyager: A Scale Model Solar System* on the National Mall in Washington D.C. Rather than tour a pre-made scale model, however, the model Sun is introduced (an ~14 cm yellow ball or large grapefruit) along with the scale factor, and then participants construct their own planet cards from a selection of common objects or by drawing the planets to scale, adding distance to the model with a planet walk done in small groups or as a class.

For middle school students to adult learners, the version of the activity using objects for taping to the planet cards includes distracters. Whereas asking participants to make predictions of the sizes of the planets relative to the Sun allows for assessment of pre-existing ideas with regard to scale, the use of distracters have shown that these ideas can be resistant to change even when the information and tools needed to create an accurate model have been provided. When used in professional development settings for teachers, as many as 1/3 of participants will select the larger distracters representing the planets after being given data tables with actual and scaled sizes and rulers with which to measure the available objects. The version of the activity described here is used as the beginning of the author’s recently completed *Stars and Planets* educator guide for grades 6-8. In *Stars and Planets* the solar system model is used as a foundation for an exploration of stars and planets beyond the solar system. However, the model is also useful for developing conceptual understanding of planetary properties and ideas known to be conceptually difficult for even adult learners, such as the reason for the seasons.

In 1987 in their groundbreaking video *A Private Universe* [8], Matthew H. Schneps and Philip M. Sadler of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics, demonstrated that even well-educated college graduates can attribute the reason for the seasons to changes in the Earth’s distance from the Sun. My own research with teachers suggests that accepting that the seasons are due to the tilt of the Earth and that the Earth has a nearly circular orbit are not necessarily sufficient to dispel this common idea. Rather, ideas of scale also play a role:

“I realized that I had combined my own theory of distance causing seasons with the correct idea of direct (concentrated) and indirect (scattered) light. Even though I knew that the cause of seasons was due to indirect and direct sunlight due to tilt, I still defined seasons as being caused by the Northern hemisphere being tilted closer to the sun or further from the sun.”

- Journal entry from 5th science grade teacher

**Why Understanding Scale Matters:** Concepts of scale have the potential to impact understand of a wide variety of concepts from the challenges of space exploration, to eclipses, to the physical characteristics and classification of the objects within the solar system, as well as fundamental concepts in astronomy. The importance of scale in understanding of basic astronomy concepts is reflected in the inclusion of questions on the topic in the creation of the *Astronomy Diagnostic Test* [9] and in the online survey on Teachers Lab, *A Private Universe Project* [10]. Data collected using both of these tools show, for example, that undergraduate astronomy students and pre-college teachers tend to underestimate the Earth-Moon difference. These findings are reflected in my own observations using the embedded assessments described here, as is the role that modeling activities can play in changing student ideas of scale in the solar system.