THE ASTEROID-METEORITE CONNECTION: DEVELOPING K-8 CURRICULUM AND ACTIVITIES IN EDUCATIONAL SUPPORT OF ASTEROID MISSIONS AND STUDIES. S. K. Croft[1,2], L. A. Lebofsky[1,3], T. L. Cañizo[1], S. R. Buxner[1,3], D. A. Crown[1], and E. Pierazzo[1], [1]Planetary Science Institute, 1700 E. Fort Lowell Rd., Suite 106, Tucson, AZ 85719 (scroft@psi.edu), [2]Science, Pima Community College, Tucson, AZ 85719, [3]University of Arizona, Tucson, AZ 85721.

Introduction: In the last 20 years, asteroids have increased in significance both scientifically and in the public eye. They have been among the principal targets of a number of spacecraft missions, including Galileo, NEAR, Hayabusa, and Rosetta. Vesta and Ceres are targets of the current DAWN mission, and a manned mission to an asteroid by 2025 is now one of the proposed main objectives for NASA. Asteroid sky surveys such as the Catalina Sky Survey, Pan-Starrs, the Sloan Digital Sky Survey, and the upcoming Large Synoptic Survey Telescope are in the news due to recognition of the importance of possible Earth impacts. Consequently, interest in asteroids is increasing among teachers and students across the nation. Scientifically, asteroids are the remnants of the material that formed the planets and their satellites. They can inform scientists, as well as students and educators, about the formation and evolution of our solar system. Although most of what we know about asteroids is derived from Earth- and space-based telescopes and spacecraft missions, meteorites provide an additional source of information – one with the advantage of allowing hands-on contact by students in the classroom.

Scientists and educators at the Planetary Science Institute (PSI) recognize the educational potential of involving students in NASA asteroid missions, large-scale telescope surveys, and direct contact with meteorites. Therefore PSI has developed a new teacher professional development workshop – The Asteroid-Meteorite Connection - as part of the Workshops in Science Education and Resources (WISER) project. This workshop is aimed at elementary and middle school teachers and addresses important questions about asteroids and meteorites: What are they? How do we study them? What do we learn from them? Why are they important?

Outline of Workshop Content and Activities:

1. Categorizing Objects. The workshop opens with a discussion of the importance and use of categorization in science, and ways to categorize objects in the solar system, including planets, dwarf planets, asteroids, etc.

2. Activity: Unexplored World. This is a hands-on group activity observing a physical "planet and satellite" model from different distances and using different techniques: ground and space-based telescopes, flybys, orbiters, landers, and sample return missions. In the activity, participants practice observing the unknown model objects and explain how inferences are made from observations. They also discuss instruments and methods for observing objects in the solar system.

3. Tour of the Solar System. This is an overview discussion of the structure of the solar system and its contents: planets, dwarf planets, satellites, asteroids, comets, and other bodies.

4. Asteroid-Meteorite Connection. An introduction to meteorites as "rocks from heaven," provides the first connection to asteroids via pre-impact meteorite orbits and observed impacts and craters in the asteroid belt. The basic meteorite types – stones (carbonaceous chondrites/CC, ordinary chondrites/OC, achondrites/AC), stony-irons/SI and irons/I – are described and characteristics provided to recognize them.

5. Activity: Classifying Meteorites. The above discussion is followed by a hands-on experience classifying meteorites using the PSI Meteorite Kits [1] according to the basic types.

6. Sky Lights: Asteroid and Meteorite Reflectance Spectra. This is a discussion reviewing the electromagnetic spectrum, introducing the concept of a reflectance spectrum, and demonstrating how such spectra can be used to explain the colors of objects and infer surface compositions.

7. Activity: Measuring a Meteorite's Reflectance Spectrum. This activity is in three parts. In the first, participants observe different colored objects through blue, green, and red cellophane "filters," qualitatively record brightness of each object at the three wavelength (colors), and draw a curve through their data to make a crude reflectance spectrum. In the second part, participants use an Alta II Spectrometer (see Lunar & Planetary Institute web site under Educational Products) to measure the reflectance spectrum of a real meteorite sample. Participants are paired together to measure one meteorite, so that several spectra are gathered by the group. The group pools the measured spectra and differences between samples are discussed. In the third part, professionally gathered meteorite spectra are compared with those measured by the group to show similarities. Then a set of asteroid reflectance spectra is provided in a graph with a transparent overlay to allow comparison of the asteroid and meteorite spectra. The observed similarities show the second asteroid-meteorite connection: using meteorite spectra to identify surface compositions of asteroids.

8. What are Little Asteroids Made Of? This discussion with demonstrations introduces the use of densities to estimate average (interior) asteroid composition. Cosmic elemental and inferred abundances of common compounds and their average densities (ices: 1, rocks: 2-3, metals: 8) allow estimation of planet and asteroid compositions from their mean densities. A graph is provided that compares object radius with density, including compression effects, and that allows participants to estimate the compositions of objects of all sizes in the solar system from tabular data. They thereby discover the composition classes of objects in the solar system: terrestrial (rock/metal), icy (rock/metal/ices), and Jovian (H/He).

9. From Dust to Planets: Formation of the Solar System. This discussion with demonstrations explores the collapse of an interstellar cloud to a gaseous solar nebula (flat, hot, rotating in one direction) by gravitational potential energy, conservation of angular momentum, and collisional damping of random motions. The condensation sequence is introduced, indicating that as the nebula cools, rocks and metals condense throughout it, whereas ices ("hydrogen compounds") condense only in the cooler part of the nebula beyond the "frost line." These first condensates are dust-like particles. By assuming that planetesimals and finally planets (by accretion) are formed from the condensed material, the the observed locations and compositions of terrestrial and icy objects are accounted for. Jovian planets form by gravitational absorption of gases. Accretion implies large craters on all solid objects, and the scattering of objects into Kuiper Belt and Oort Cloud. Meteorites provide the age of solar system formation via radiometric dating; granular structure of some meteorites represents the original dust condensates in the solar nebula.

10. Stories the Rocks Can Tell. This discussion with demonstrations reviews terrestrial rock types (sedimentary, volcanic, metamorphic) and the rock cycle on Earth. Processes important in meteorites are emphasized: burial and compaction of fragmental materials (lithification without heating), aqueous alteration (clays), mild heating and metamorphism, significant heating with melting and differentiation, impact brecciation, lithification, and melting (chondrules and tectites)

11. Activity: Processes Affecting Meteorites. In this second activity involving the PSI Meteorite Rock Kits, participants identify major processes that have affected meteorites: OCs and CCs are undifferentiated: lithified without significant heating (presence of carbon and hydrated minerals, flecks of pure metals); OCs with indistinct chondrules have been metamorphosed by mild heating; ACs, Is, and S-Is have been melted and differentiated; chondrules and breccias have been formed via impacts on planetesimals. This activity ends with a group discussion of the processes identified and connection of these meteorite processes to processes on the meteorite "parent bodies" – the asteroids. They infer that some asteroids are undifferentiated, some are differentiated into cores, mantles, and crusts, and all have been impacted – some catastrophically as inferred from samples of irons (cores) and stony irons (lower mantles).

12. Activity: Putting it all together: Tales of Three Asteroids. In this culminating activity, data are provided for each of three asteroids Ceres, Vesta, and Hebe: orbital radius, asteroid dimensions, mean density, and the reflectance spectrum. Using the techniques discussed and practiced earlier during the workshop, participants derive estimates of surface composition (from the spectrum) and mean composition (from density and dimensions). From these conclusions, participants can infer whether the asteroid is differentiated or undifferentiated, and some events in the geohistory of each. (These three asteroids were chosen because Ceres is the largest asteroid and a target of DAWN, and the meteorite kits include samples from Vesta (also a DAWN target) and Hebe – so the participants actually handle pieces of two of the asteroids they study!)

13. Summary Session. The content above is presented in two 4-hour workshops on successive weekends, followed by a 2-hour mid-week session where questions are answered and evaluation materials are completed [2, 3, 4].

Summary Comments: We have run this workshop twice, refining the content, discussions, and activities each time based on participant reactions. In general, the participants grasped most of the content, which is admittedly challenging. The identification of processes in meteorites was difficult because of complexity of some meteorite samples, and the unfamiliarity of many participants with rocks in general.

On the other hand, we have developed content and activities that can be used at different grade levels in support of asteroid educational efforts. These materials will shortly be made available online.

References: [1] Lebofsky L. et al. (2011) *This volume*. [2] Croft S. K. et al. (2011) *This volume.* [3] Cañizo T. L. et al. (2010) *LPS XLI*, Abstract #1164. [4] Lebofsky L. et al. (2010) *LPS XLI*, Abstract #1192.