MOON ZOO: LESSONS LEARNED FROM THE FIRST YEAR OF CITIZEN SCIENTISTS IDENTIFYING LUNAR CRATERS. S.J. Robbins[1,2], C.R. Chapman[2], P.L. Gay[3] [1]LASP, UCB 392, University of Colorado, Boulder, CO 80309. [2]Southwest Research Institute, Suite 300, 1050 Walnut Ave., Boulder, CO 80309. [3]Center for STEM Research, Education, and Outreach, Southern Illinois University Edwardsville, Edwardsville, IL 62026

Introduction: Moon Zoo launched in May 2010 as a citizen science initiative to have members of the public assist researchers in identifying craters, boulders, and "interesting features" on the lunar surface from *Lunar Reconnaissance Orbiter* (LRO) Camera (LROC) Narrow-Angle Camera (NAC) images.

Science Objectives: Moon Zoo's objective is to provide the largest, most robust, and geographically broad catalog of lunar craters by crowd-sourcing the data-gathering process [1]. Users are also identifying boulders and using a simple ranking task to produce a "boulderiness" density map of the lunar surface. Analysis of 10s to 100s of meters-sized craters seeks to help answer several basic questions in lunar science.

- Determine relative ages and lunar stratigraphy through crater size-frequency relationships and comparison with published isochrons [2, 3].
- Constrain and refine the sub-kilometer production function of craters on the moon.
- Examine the thickness of the lunar regolith through ejected boulders and concentric-ring craters.
- Map the distribution of boulders to create a relative boulder density map of targeted areas.
- Identify and catalog unusual/interesting geologic features and special crater types, including bright-ray, dark-haloed, concentric-ring (or "bench craters" as they are referred to in Moon Zoo), as well as spacecraft hardware.

Current Status: Moon Zoo has been operating for approximately 16 months. In that time, it has attracted approximately 45,000 volunteers from around the world with the majority based in the United States of America and Great Britain. From forum discussions on the website, volunteers range in age from young school children to those in their 70s and 80s. In terms of craters, volunteers have made over 4.3 million individual crater annotations in that time.

As is common with other volunteer-based website collaborations, roughly half of Moon Zoo users have made 0 or 1 classifications [4]. Approximately 1/3 of volunteers have made 10-100 classifications. Even though <10% of users have made >100 classifications, these represent ~77% of all craters marked. Roughly 0.05% of users (~10 people) have made more than 10,000 crater classifications, representing 13.5% of all crater markings [4].

The roughly 4.3 million classifications have been preliminarily reduced to a crater catalog with ~600,000 entries. Current work is actively focusing on revising how lunar citizen science is done based upon the lessons learned from the first year of operations.

Issues Faced, Lessons Learned, and Future Changes: There are several aspects of Moon Zoo that we are working on to improve over the next few months to gather better data and make the experience a more beneficial one for both users and scientists:

Mandatory Tutorial: Of the ~45,000 volunteers, approximately 10% of them have completed the tutorial which currently consists of a video and example images. We have nearly completed a new interactive tutorial that guides the user on how to correctly mark and submit their craters and use other aspects of the Moon Zoo interface. By request from the volunteers, we are working on including an updated video tutorial as a companion. We also will be making the tutorial mandatory based upon interesting quirks in the first year's data. Mainly, these include the minimum crater size (addressed below) and an interesting phenomenon whereby many people will mark just the region of a deep crater that is in total shadow as the crater, as opposed to the actual crater rim. With multiple people doing this, it makes it through the data reduction process that utilizes a clustering algorithm to merge multiple classifications of (hopefully) the same crater into a single, final crater.

Minimum Crater Sizes: The minimum crater size in the current Moon Zoo interface is capable of marking a 10-pixel-radius crater. We have learned that some users do not resize craters nor understand that the tool should not be used to mark craters smaller than the minimum size. In our data reduction process, we have integrated a first-level rejection that removes all classifications that are the minimum size. Unfortunately, this has removed approximately 1/3 of the annotations made. In the next few months, we plan on changing the crater tool to work like a standard circle-drawing tool in graphics software. When the circle is too small, it will appear red or not save the crater. A circle at or above the minimum radius will appear green and be saved on-screen and to our database.

Removing Elliptical Crater Marking Ability: Users can, after creating a circular crater, use the tools in Moon Zoo to change the major and minor axes and rotate the crater. However, we have found that this is not reliable nor consistently used in a robust manner across different users (<5% of users have actually taken advantage of this capability). Consequently, we will be removing it from future iterations of the marking tool.

Map Projecting Images: For various reasons, LROC NAC images were not georectified when imported into the Moon Zoo pipeline. This means that for images taken at different slews, every crater in the image appears to be elliptical, both confusing the users and data reduction. For the new image release that will be taking place within the next month, images will be fully processed using the USGS's ISIS 3 software. Crater data are stored on the server in units of degrees latitude and longitude for position and meters for diameter. The processed ISIS .CUB file is retained, as well. This will allow us, if necessary or desired in the future, to back-project the data to pixels on the original NAC frame and then use a new calibration to then re-project the data into a refined coordinate system.

Expert Classifications, User Weighting, and Checking Work: An ongoing process that we are working on is to develop and refine a user weighting system whereby users are ranked and given a score in terms of how well they classify craters relative to expert classifications. A tree-like approach is used here: First, experts in the field will have cataloged several craters in the same images as volunteers. Second, volunteers that have looked at any of the same images as experts will then be compared with those experts on the images and assigned a score based on how well they match. Third, users who were "once removed" (did not look at any images experts had, but did look at some images that users in step two did) are compared with the users from step two and given a ranking. This process continues for one more step (two degrees of separation from the experts) but not further because the ranking gets more uncertain the further removed from the experts it is.

For that reason, in the future, we also plan on having a set of already expert-classified images to draw from whereby users will unknowingly, every several images, be presented with one that has a "known" set of craters and they will be scored against that set. This will serve several purposes: (a) It will identify users who may be in need of "remedial" training on an extended tutorial, (b) it will increase the validity of our results when users consistently score well, (c) we can continuously update the user weighting system, and (d) we can provide feedback to the users about how "well" they are doing. On this last point, despite the original thinking that users should not be told how they are doing for fear of contaminating the results, we think that providing limited feedback every two dozen images (or so) will satisfy the number-one request of users for more feedback.

Future Interface Tasks: We are actively working on refining the current Moon Zoo tasks and tools and planning future lunar citizen science tasks. One such task will present a section of a NAC image that has been run through an automated crater detection algorithm. Users will be asked to accept, reject, change, and add craters based on the automated software's markings. The hopes are (a) that this will help speed annotations if the majority of craters are already well marked, (b) increase users' interest by providing a game-like atmosphere, and (c) provide feedback to automated crater detection researchers who are working on revising their software.

Another task we plan to create is where users can search for and identify linear features, marking them with a simple line tool. The goal for this task is to map out volcanic and tectonic features across the planet at a finer scale than any single researcher or group can do themselves. A third plan is to provide an advanced-user task that will focus on having volunteers only search for and classify "interesting" types of craters and linear features. In this task, they will learn to differentiate, for example, between volcanic and impact-melt dark-haloed craters. They will also help differentiate between graben, wrinkle ridges, and scarps.

Discussion: Citizen science projects offer researchers the resources of vast numbers of people to do basic image analysis that is still much better done by humans than computers. For lunar crater recognition, a seemingly simple task was set up and launched to the world in May 2010. Over the past 15 months, we have learned a lot about how the public looks at these kinds of images and identifies features. We are actively revising the interface for lunar citizen to better address the needs and abilities of the users and thus collect more robust data in the future.

References: [1] Joy *et al*. 2011. [2] Neukum et al. 2001. [3] Stöffler et al. 2006. [4] Huang et al. 2011, (in prep.).