Citizen Science: Status and Research Directions for the Coming Decade

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SUMMARY

Imagine a world where participating in science is as accepted a part of everyday life as participation in a sport is today. Many people would participate in science at various levels, each making genuine contributions to scientific knowledge. How much more knowledge could we discover? How many more people could learn about the way that science works and make scientific habits of mind a part of their everyday lives?

Such a world is starting to become a reality through **Citizen Science**. Citizen Science involves volunteers from the general public in scientific investigations as data collectors or analysts. A number of existing Citizen Science projects in astronomy have been highly successful in terms of scientific productivity and number of people reached.

Citizen Science has a number of benefits for four separate communities. For scientific researchers, it allows projects that were previously impossible to be done quickly and easily. For volunteers, it can provide fun, a sense of community, and the ability to contribute to science. For STEM educators, it can offer the opportunity for increased learning, a window into the process of science, and a chance to promote the idea that "I can do science." For society at large, it can build a closer connection between scientists and the public, and can result in a public with increased knowledge about science and scientific habits of mind.

We strongly recommend that the astronomical community recognize the value added by Citizen Science to astronomy, in terms of both its scientific merit and its broader impacts. We recommend that developers of Citizen Science projects collaborate to share tools and lessons learned, as well as engage in formal research studies to quantify characteristics of successful Citizen Science projects as measured by all stakeholders.

I. The Need for Citizen Science

Citizen Science involves volunteers from the general public in scientific investigations as data collectors or analysts. The term "Citizen Science" has traditionally been used when some aspect of the data collection or analysis is beyond the capacity of the core science team, but is doable by a distributed network of volunteers, as happens with weather data collection projects[1] and bird or other organism censuses that happen simultaneously over a large area.[2,3] But recently, Citizen Science has moved to a web-enabled mode of operations and expanded into new and innovative domains. In astronomy, these new projects have evolved out of a clear need faced by astronomers and other scientists for analyzing and interpreting massive scientific datasets.

Improvements in detector and computer technology mean that the amount of available scientific data is currently doubling every year,[4] while the number of professional scientists available to interpret the data grows much more slowly. This "data deluge" is a critical problem in astronomy today; one of today's largest astronomical surveys is the Sloan Digital Sky Survey (SDSS), whose total data size is about 60 terabytes[5] – similar in scale to the entire data holdings of the U.S. Library of Congress.[6] By the end of the coming decade, the Large Synoptic Survey Telescope (LSST) will be producing a similar amount of data as the SDSS *every night.*[7]

The coming data deluge means that to maximize the scientific output of these upcoming large surveys, we must develop new methods to make productive use of very large datasets. Some types of scientific problems (such as those that require pattern recognition in images) are very

difficult for computers, even though they are trivial for humans;[8] but the data deluge means that even large teams of professional scientists cannot visually examine entire datasets.

Citizen Science offers a solution to this problem.[9] Citizen Science is based on the realization that most of the tools and data resources necessary to do research in astronomy are freely available online, and that many of the skills required for scientific research are already possessed by many members of the general public. This approach offers the promise of a large team of volunteer Citizen Scientists that is ready, willing, and able to discover new knowledge alongside professional scientists.

Citizen Science is driven by a scientific need, but it simultaneously meets an identified need for authentic science experiences in both formal[10] and informal[11] education. Citizen Science experiences are by definition authentic science experiences – volunteers study exactly the same data that professional astronomers study, use many of the same tools, and contribute to the same scientific journals that professionals do. The power of Citizen Science is that it can meet the needs of both science research and science education at the same time.

II. The State of Citizen Science

Citizen Science has been practiced since at least the 1700s[12], but a number of factors are now coming together to accelerate its development and to evolve it in new directions. As described above, new large-scale surveys are bringing more data to the public. At the same time, advances in data storage and web technology are making those data, including images, easier for volunteers to access,[13,14] and social networking technologies such as forums and blogs are allowing communities to form around a shared interest in scientific research.[15]

In astronomy, Citizen Science has been practiced for more than a hundred years by the American Association of Variable Star Observers (AAVSO)[16] and similar organizations in which amateur astronomers have teamed up with professionals to publish papers. Examples of more recent online astronomy Citizen Science projects, which have lower barriers to entry, include Stardust@home,[17] in which volunteers search for tiny dust grains in aerogel returned from NASA's Stardust spacecraft; GLOBE at Night,[18] in which volunteers around the world use the number of stars visible in Orion as a measure of light pollution; and Galaxy Zoo,[19] in which volunteers classify images of galaxies.

Starting in June 2007, Galaxy Zoo asked users to look at images of galaxies from the Sloan Digital Sky Survey (SDSS) and to record the shape and direction of rotation of galaxies by clicking one of six onscreen buttons. Before stepping in to classify, users are taken through a simple tutorial about galaxy types, and are tested on what they have learned to ensure that they have enough basic skill to produce reliable classifications. Within its first year online, almost 150,000 volunteers from across the globe participated in Galaxy Zoo, providing over 50 million classifications of galaxy images. Comparison of Galaxy Zoo volunteer classifications with a published sample of expert-classified galaxies[20] shows that the classifications agree to a high level.[19]

Scientists are using the results of these galaxy classifications to complete more than 25 different research projects. Four published papers have resulted from the Galaxy Zoo dataset, with the following titles:

- "Galaxy Zoo: The large-scale spin statistics of spiral galaxies in the Sloan Digital Sky Survey"[21]

- "Galaxy Zoo: Morphologies derived from visual inspection of galaxies from the Sloan Digital Sky Survey"[19]
- "Galaxy Zoo: Chiral correlation function of galaxy spins"[22]
- "Galaxy Zoo: the dependence of morphology and colour on environment"[23]

Several more papers are currently undergoing peer review. None of these projects would have been possible had it not been for the large, high-quality dataset of galaxy morphologies that Galaxy Zoo volunteers produced.

Galaxy Zoo includes a blog (www.galaxyzooblog.org) where the research team writes about the research that they are conducting, and volunteers ask questions and receive answers in the comments section. The project also has a forum (www.galaxyzooforum.org) where volunteers communicate with one another. The forum has served as a gathering place for some members of the volunteer community, where volunteers share images of beautiful galaxies that they have seen while classifying, discuss Galaxy Zoo research projects, and ask and answer questions about astronomy. A key component of the forum is that Galaxy Zoo project scientists ("Zookeepers") also participate; as of March 12, 2009, "Zookeeper" Kevin Schawinski of Yale University had more than 1,400 posts. The forum has also served as a place to coordinate meetups between volunteers in real life.

The forum was also responsible for one of the most stunning discoveries made by Galaxy Zoo so far – an object known as "Hanny's Voorwerp," discovered by Dutch primary school teacher Hanny Van Arkel (voorwerp is Dutch for object). Follow-up observations on large telescopes have shown that the object is likely a light echo from a long-dead quasar. Future observations are scheduled on the Hubble Space Telescope. Hanny's Voorwerp is clearly viewable in SDSS Data Release 6 images, but the first person to recognize it as potentially interesting was a Citizen Science volunteer. It likely would have remained forever undiscovered had it not been for volunteers posting on the Galaxy Zoo Forum.

One of the most amazing results of Galaxy Zoo has been the way in which its forum has enabled volunteers to work on self-identified community research projects. The most striking example of such research is a project to classify irregular galaxies. The project was initiated from a question posed by volunteers, and the volunteers are now conducting the research using tools of modern astronomy research, as well as online tools that they wrote themselves. Their ultimate goal is to publish a journal paper with community volunteers as primary authors. The irregular galaxies project, and others like it, have resulted in volunteers teaching themselves about scientific content, using tools of modern astronomy data, and working as scientists.

As a result of our experience with the blog, forum, and volunteer-initiated projects, we have identified "Levels of Engagement" in Citizen Science, in which volunteers move from the main Citizen Science task such as classifying galaxies (Level 1), to participating in the community such as the forum and blog (Level 2), to working independently on self-identified research projects (Level 3). This process of increased involvement has been documented as a cycle of activity central to becoming a knowledgeable participant in various professional communities.[24]

The next step in the Galaxy Zoo project, currently ongoing, is "Galaxy Zoo 2," which asks volunteers to classify galaxies in a more detailed classification scheme, using a branching series of questions such as whether a given spiral galaxy has a bar or a ring, the number of spiral arms, and how tightly the arms are wound. Galaxy Zoo 2 launched in February 2009; so far, it has attracted the same excitement that the original Galaxy Zoo did.

Today, a number of scientists and educators, including those on our team, are actively engaged in designing, developing, and implementing new Citizen Science projects. With this

increased interest in Citizen Science, it is of paramount importance to the astronomy community to understand how Citizen Science works, and how Citizen Science can provide the most benefit to all its constituencies.

III. A Vision of Citizen Science in the Coming Decade

Our vision for Citizen Science in the coming decade is to create an environment in which participation in Citizen Science is as commonplace and accepted as participation in a sport is today. Today there are very few professional basketball players, but many people play amateur basketball at various levels, from recreational leagues to shooting at backyard baskets. All these participants are playing the same game of basketball, but only a few are able to score points for a professional team; in contrast, with Citizen Science, even hobbyists who participate occasionally and casually can make genuine and important contributions to science.

In our vision for the future of Citizen Science, many people would participate in Citizen Science at various levels of engagement. Some would participate by engaging in the central Citizen Science task (in the case of Galaxy Zoo, this was classifying galaxies, but future Citizen Science projects might have other tasks such as recording measurements on images). Some would participate by interacting with the volunteer social network through blogs, forums, or other social networking technologies of the future. Some would initiate projects and work with guidance from scientists to write and publish their own research papers.

In a society where Citizen Science is commonplace, how much more scientific knowledge could we discover? How many more people could learn about the way that science works and make scientific habits of mind a part of their everyday lives?

In the rest of this section, we will describe the benefits that our vision of Citizen Science has for four separate stakeholders: the scientific community, the volunteers, the education community, and society as a whole. In the next section, we will make recommendations for realizing this ambitious vision within the next decade.

Benefits to the Scientific Community

Citizen Science is first and foremost a scientific endeavor in which volunteers from the public work with professional scientists to conduct publishable research. Citizen Science allows scientists to complete research projects that they could have never done without involvement of public volunteers. Categories of such projects include:

- *Reporting measurements taken over a wide area or very short timescale*: Coordinated networks of amateur astronomers have long collected high-quality observational data that professional astronomers have used, through organizations like the AAVSO and through one-on-one pro-am collaborations. Such observations can be conducted on a worldwide scale, allowing for continuous, short-timescale observation of objects and coverage of both hemispheres. Even in the age of LSST's one-week-scale repeat observations, there will be a place for distributed Citizen Science observations in fields like variable stars and rotating asteroid light curves.[25]
- *Finding the needle in the haystack*: Citizen Science is useful for finding rare objects that can be identified only by visual inspection. These rare objects include the dust grains that

Stardust@home is searching for.[17] Other possible rare objects include arcs from gravitational lenses such as the SDSS's "8 o'clock arc."[26]

- *Quick, accurate analysis of very large datasets:* Citizen Science can enable classification of large numbers of objects quickly. For example, the original Galaxy Zoo sample contained nearly 900,000 galaxies; within a week, each galaxy had been classified multiple times. Galaxy Zoo volunteer classifications agree with a published sample of expert-classified galaxies[20] to a high level.[19] Studies in other fields of science also show that Citizen Scientists produce accurate data.[27]
- *Exploration of parameter spaces in simulations:* Citizen scientists can visually compare the results of computer simulations to observed images. Such an approach would be useful in simulating a variety of scientific phenomena, particularly galaxy mergers.[28] With the help of simple, fast-running restricted 3-body models, Citizen Scientists can provide valuable help in identifying likely starting configurations for simulations of hundreds of merger systems, an order of magnitude greater than the number of merger systems studied in detail today.
- *Serendipity:* As was the case with Hanny's Voorwerp, Citizen Science can stumble across new and unexpected discoveries. Who knows what new types of astronomical objects future Citizen Science projects might find – objects that we do not yet even know to look for!

Benefits to the Volunteers

Citizen Science also offers immediate benefits to the volunteers who participate in it. Some of these benefits may include:

- *Enjoyment*: Many volunteers find Citizen Science activities to be fun. Some volunteers have said that because classifying a galaxy in Galaxy Zoo immediately brings another galaxy, the Galaxy Zoo interface feels "addictive." Future Citizen Science projects will offer a variety of experiences, which will allow many types of people to find projects they enjoy.
- *Social community:* Citizen Scientists receive the benefit of participating in the social community enabled by networking tools such as the forum and blog, and meetups in real life. As future Citizen Science projects grow, and as social networking technologies improve, more Citizen Science-related social communities will evolve.
- *Ability to participate in real science:* Citizen Science allows volunteers to participate in real scientific projects, and to be recognized for this participation. All Galaxy Zoo papers include a footnote acknowledging the contribution of all Galaxy Zoo volunteers;[19] future papers will also recognize special contributions of individual volunteers. Part of this ability to participate in real science is the possibility that a volunteer could be the first person to make a discovery – for example, a rare object like Hanny's Voorwerp or a dust grain in Stardust@home (Stardust@home will make volunteers co-authors on papers announcing these discoveries).

Benefits to the Education Community

Citizen Science also offers exciting opportunities to promote science literacy in its audience of distributed worldwide volunteers. As defined by the American Association for the Advancement of Science in its landmark *Science For All Americans*,[29] science literacy entails understanding facts and concepts in science domains; understanding the process and methods of science; understanding of the ways in which scientists think about the world; and understanding the two-way relationship science has with the larger world, society, and technology. Citizen

Science has the potential to impact science literacy in learners in many ways, including:

- *Opportunity for direct communication with scientists:* Communication with project scientists through forums and meetups offers the opportunity for volunteers to ask questions of scientists one-on-one, and presents living examples of what scientists are like.
- *Increased content knowledge:* Citizen Science takes place within science domains, is built on principles of engineering and technology, and requires mathematics to correctly interpret. Thus, Citizen Science can touch content from all components of STEM education. Studies at the Cornell Laboratory of Ornithology show that a Citizen Science project there did increase volunteers' knowledge of bird biology.[30]
- *An experience of the process of science:* Because Citizen Science is by definition authentic science, an experience of Citizen Science gives volunteers experience in the process of science. Volunteers see what data look like, how data are collected and analyzed, how data analysis leads to evidence-based conclusions, and how scientists communicate with one another and publish results. Existing Citizen Science projects have seen volunteers move from doing a data task to asking questions of scientists, and even to initiating and leading new research projects. In doing so, they become more aware of and enmeshed in the activity of science and become more knowledgeable participants in the scientific community.[24]
- *Opportunity for changes in attitude toward science:* Science is often perceived as being done in isolation by old white men, as illustrated by student drawings of scientists in the well-known "Draw-a-Scientist" test.[31] Because volunteers know that they are making real contributions to science, they can develop an attitude of "I can do science."

Benefits to the Society as a Whole

Citizen Science could also lead to major benefits to society as a whole, including:

- *Closer connection between scientists and the public:* The public often sees science and scientists as being different and distanced from everyday life. Bringing the public and scientists together as partners through Citizen Science can help to remedy this situation. Carr[32] discusses many benefits of Citizen Science, including the possibility that Citizen Science can "rebuild and rekindle some of the public trust lost in institutional science."
- *Increase in scientific understanding and habits of mind by the public as a whole*: The more the public is involved in any scientific endeavor, the more they are exposed to the concepts and vocabulary of the subject matter being studied. Research shows that as time goes by, volunteers learn the scientific content necessary for meaningful participation.[30] Also, the opportunity for scientific discussion among participants increases. Through forums, email, chat, or face-to-face discussions, participants "talk science" both among themselves and with scientists. Trumbull et al.[33] see suggestions of scientific thinking by reviewing letters written by over 700 Citizen Scientists to the Cornell Ornithology Lab. More than 80% of these letters showed evidence of scientific thinking on the part of the volunteers. The researchers credit the Citizen Science project for providing a forum for scientific communication.

IV. Recommendations

To make this vision of Citizen Science into a reality, we make the following recommendations to the astronomy community. These recommendations are based on our experience in developing Citizen Science projects and our initial research explorations into how Citizen Science works.

- **Recognize volunteers as research collaborators, identifying them collectively, and by name when possible:** When Citizen Science projects recognize volunteers, as Stardust@home and Galaxy Zoo do today, they provide an incentive for increased engagement and give volunteers ownership of the results. Where possible, as in the case of Stardust@home's dust grains or Hanny's Voorwerp, volunteers should be recognized individually and by name.

- **Encourage development of citizen science projects such that old projects can bridge into new projects, with the same volunteer community and standard interfaces:** A number of highly successful Citizen Science projects are already online, with large populations of highly committed volunteers. Many of these projects will naturally reach an endpoint when volunteers have analyzed all their data, and their scientific goals are reached. Rather than letting these volunteer communities disperse, our community should leverage them to become the initial audiences of new Citizen Science projects; as new projects come online, several should run simultaneously, sharing volunteers among different projects. We recommend that developers create a standardized set of web-based software to allow volunteers to use a standard interface for many different Citizen Science projects, lowering barriers to entry into new projects. As a consequence of these recommendations, we recommend that designers of existing and new Citizen Science projects work closely together to establish and implement best practices in Citizen Science project design.

- **Develop an understanding of how to "calibrate" user contributions into science data:** What Citizen Science initially produces is a series of actions contributed by thousands or millions of distributed volunteers – web clicks, measurements, images, or other types of operations. The finished product of Citizen Science needs to be a science-ready dataset that can be interpreted to make meaningful discoveries. How can projects move from the "raw data" of user actions to the needed "science-ready data products"? For Galaxy Zoo, where the raw data was clicks on a web site, calibration involved iteratively upweighting and downweighting certain users, applying their weights to classifications, and finally spot-checking the classifications against expert classifications.[19] This calibration process is likely to be different for each Citizen Science project, based on the project's goals and the actions required of the user, and will likely involve advanced statistical algorithms.

- **Study who participates in Citizen Science, and what motivates them to participate at various levels of engagement:** To build further participation in Citizen Science, it is important to know who volunteers. Although studies have been done of audience demographics of Citizen Science efforts in other fields[34] and of other online communities interested in astronomy education,[35] astronomical Citizen Science is new enough that little has been written about who participates. We recommend study of audience demographics through audience surveys or other methods. An even more critical question for designing future projects in Citizen Science is, "*Why do people choose to volunteer their time to*

participate?" Once we understand what motivates different groups of volunteers to participate in Citizen Science, we can better design future projects to appeal to people approaching Citizen Science with those motivations. Data on motivations can be collected through surveys, interviews, and postings on forums; these data can be analyzed using methods based on Grounded Theory.[36] Such research into motivation should be conducted to determine the motivations of volunteers who engage at all possible levels of Citizen Science, from performing the basic task to engaging in deep, self-directed research using tools of modern astronomy.

- **Research what tasks and datasets are most appropriate for Citizen Science, and develop pilot activities that use those tasks and datasets:** A large variety of different tasks and datasets make potentially viable Citizen Science activities. These tasks and datasets can, to an extent, be varied independently of one another – for example, Galaxy Zoo 2 involves a different task using the same dataset (SDSS images) as the original Galaxy Zoo, while one could easily imagine a Galaxy Zoo (1)-like project being done with black-and-white Digitized Sky Survey images. These variations would offer an opportunity for natural experiments to study which tasks and datasets are most appropriate for Citizen Science. To get a sense of the effects of new tasks and datasets on volunteers, researchers may use a variety of methods, including surveys and the grounded theory-based analysis of forum posts and/or interviews. Participants may be observed and interviewed in-person (perhaps in science museums) as they move through different sets of data, and/or before and after completing certain tasks.

- **Assess what volunteers learn about science content and process, and how participant attitudes toward science change, and develop resources to maximize learning:** A major case for Citizen Science is that it addresses an identified need for authentic science experiences in STEM education. To clearly make this case, we must develop an understanding of exactly what participants learn from engaging with Citizen Science at various levels. Studies of the Cornell Lab of Ornithology show that a Citizen Science experience developed there did increase participant knowledge of bird biology,[30] and that study and another[33] suggest that participants can think more scientifically as a result of participation. To understand what participants learn from online astronomy Citizen Science projects, we recommend development of concept inventories for concepts addressed in Citizen Science projects that are validated with a population of adult web-based volunteers. Our community can use existing instruments like the Astronomy Diagnostic Test[37] as starting points. Research into participant attitude will require instruments to measure participant attitude,[38] and/or interviews and surveys with participants. Once we understand what volunteers learn from Citizen Science participation, we can create resources to improve STEM learning in Citizen Science volunteers. These resources should be made freely available online to volunteers and should be shared among Citizen Science projects, and assessed through diagnostic tests, surveys, participant observations, and other methods.

- **Develop research-based ways to incorporate Citizen Science into K-12 and museum educational experiences:** At present, the audience of Citizen Science is entirely self-selected, mostly adult, and online. However, there is a massive, mostly-untapped potential for developing new Citizen Science volunteers from among the 96 million annual visitors to

U.S. science and technology museums and the 75 million total K-12 students in the U.S. If Citizen Science activities could be incorporated into K-12 curricula, and/or could be offered on the floor of science museums and planetariums, a new audience of Citizen Scientists could be recruited. The methods developed should be based in education research of what makes citizen science in these settings successful.

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