Improving Crowdsourcing and Citizen Science as a Policy Mechanism for NASA

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ABSTRACT

This article examines citizen science projects, defined as "a form of open collaboration where members of the public participate in the scientific process, including identifying research questions, collecting and analyzing the data, interpreting the results, and problem solving," as an effective and innovative tool for National Aeronautics and Space Administration (NASA) science in line with the Obama Administration's Open Government Directive. Citizen science projects allow volunteers with no technical training to participate in analysis of large sets of data that would otherwise constitute prohibitively tedious and lengthy work for research scientists. Zooniverse.com hosts a multitude of popular space-focused citizen science projects, many of which have been extraordinarily successful and have enabled new research publications and major discoveries. This article takes a multifaceted look at such projects by examining the benefits of citizen science, effective game design, and current desktop computer and mobile device usage trends. It offers suggestions of potential research topics to be studied with emerging technologies, policy considerations, and opportunities for outreach. This analysis includes an overview of other crowdsourced research methods such as distributed computing and contests. New research and data analysis of mobile phone usage, scientific curiosity, and political engagement among Zooniverse.com project participants has been conducted for this study.

INTRODUCTION: CITIZEN SCIENCE AND THE U.S. GOVERNMENT

On the first day of his position in office, President Barack Obama gave the Memorandum on Transparency and Open Government his inaugural signature. The memorandum states that the American government should be transparent ("put information about their operations and decisions online and readily available to the public"), participatory ("offer Americans increased opportunities to participate in policymaking"), and collaborative ("use innovative tools, methods, and systems to cooperate…across all levels of Government and with nonprofit organizations, businesses, and individuals in the private sector"). These three traits make up the Open Government Principles. It directed the White House chief technology officer to work with the director of the Office of Management and Budget and the Administrator of the General Services Administration to develop recommendations for an Open Government Directive, laying out specific actions to be taken to forward these three principles.[1]

This article will focus on the participatory and collaborative principles, specifically with regard to how the continued use and development of innovative crowdsourced research and citizen science can benefit the National Aeronautics and Space Administration (NASA) and other space-related groups. Citizen science does not yet have a single widely accepted definition. A product of the Internet, it is relatively new to science, is still evolving, and exists in a multitude of forms. This discussion will use the terms "crowdsourcing" and "citizen science" as defined by the Federal Community of Practice for Crowdsourcing and Citizen Science (FCPCCS):

- Crowdsourcing: "a process where individuals or organizations submit an open call for voluntary contributions from a large group of unknown individuals ('the crowd') or, in some cases, a bounded group of trusted individuals or experts"
- Citizen science: "a form of open collaboration where members of the public participate in the scientific process, including identifying research questions, collecting and analyzing the data, interpreting the results, and problem solving."[2]

Although the FCPCCS does not include prizes and challenges in its definition of crowdsourcing, some discussion of these methods will also be included in this article. The primary focus of this research is citizen science projects conducted over the Internet, often in a "gamified" format.

The first resulting document from the Memorandum's call to action was the Open Government Directive issued in December 2009, which established deadlines for executive agencies and departments to take specific action toward the development of individual Open Government Plans (OGPs).

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The directive laid out a list of requirements detailing relevance to the three Open Government Principles in addition to mandating the creation of publicly accessible websites pertaining to these goals. It states that "the Federal Government should promote opportunities for the public to participate throughout the decision-making process," suggesting agencies describe "new feedback mechanisms, including innovative tools and practices that create new and easier methods for public engagement." Additionally, each agency is required to "revise its current practice to further cooperation with… the public and non-profit and private entities in fulfilling the agency's core mission activities," to "include proposals to use technology platforms to improve collaboration" and "include innovative methods, such as prizes and competitions." The OGPs are to be updated every two years.[3] NASA released version 3.0 in June 2014.[4]

Building upon the Memorandum on Transparency and Open Government and the Open Government Directive in addition to collaboration with groups both inside and outside the federal government, White House policymakers developed a National Action Plan (NAP) to illustrate progress made on various Open Government efforts and lay out goals for advancing these initiatives. The first U.S. Open Government National Action Plan, released in September 2011, included 26 different areas of commitment for federal agencies. One of the included goal categories, "Open Government to Improve Public Services," touched upon helping scientists by promoting the publication of guidelines on curating unclassified scientific data supported by funding from federal science agencies. The NAP also asked that agencies "Promote Innovation Through International Collaboration," launching the International Space Apps Competition as a collaboration between NASA and other space agencies worldwide to enable scientists and interested citizens to solve challenges through publicly available data.

Building upon its predecessor, the Second Open Government National Action Plan for the United States of America was released in December 2013. It reported that 24 of the initial 26 commitments had been completed and thus launched new initiatives in addition to expanding and developing further the existing commitments. The 2013 NAP advocated for the creation of an "open innovation toolkit" for federal agencies "that will include best practices, training, policies, and guidance on authorities related to open innovation, including approaches such as incentive prizes, crowdsourcing, and citizen science."

The 2013 NAP also calls for an increase in crowdsourcing and citizen science programs, citing efforts currently in place by NASA, the Environmental Protection Agency (EPA), the National Archives and Records Administration (NARA), and the U.S. Geological Survey (USGS).[5] The federal government has taken advantage of citizen science and crowdsourcing to contribute to agencies' missions with success in a number of areas. The EPA has introduced "volunteer monitoring" in procuring data about water quality, which it uses for "delineating and characterizing watersheds, screening for water quality problems, and measuring baseline conditions and trends." In addition to data collection, the EPA notes that volunteers also gain knowledge in pollution prevention, help clean problem areas, and provide information on areas that would otherwise be overlooked.[6]

The NARA Citizen Archivist Dashboard provides volunteers access to projects that include tagging images and documents, historical film captioning, and transcription of federal records. These activities have produced notable results; over 170,000 volunteers indexed 132 million names from the 1940 Census in 5 months. One of its most successful programs is *Old Weather*, a ship log transcription program hosted by Zooniverse.org, an online platform hosting a variety of citizen science projects across multiple disciplines, and operated in partnership with the National Oceanic and Atmospheric Administration (NOAA). *Old Weather* will be addressed in greater detail later in this article.

The USGS uses volunteers from its *National Map* Corps program to collect and improve structure data for the *National Map* using a web-based mapping tool. The *National Map* Corps began in 1994 as the Earth Science Corps, which used volunteers to identify and annotate article maps. In 2001, the Earth Science Corps was renamed and refocused toward collecting data on built structures in the United States using handheld GPS units. From 2003 to 2006, almost 23,000 data points were contributed by over 1,000 volunteers. The program then evolved to a web-based format in 2006, with the GPS input system being suspended in 2008 due to funding issues.[7]

USGS's "Did You Feel It?" earthquake response system enables people worldwide to document their experiences during and immediately after earthquakes. Questionnaire responses contribute to the creation of Community Internet Intensity Maps (CIIM), which are generated nearly instantly, compared to the months it would otherwise take to prepare and distribute a shaking-intensity map. The CIIMs provide descriptions of earthquake shaking due to what contributors directly experienced rather than inferring the effects from strong-motion seismograph records.[8]

As part of NASA's compliance with its OGP, the International Space Apps Challenge was introduced in 2012 as a 2-day "hackathon" to take place in over 25 cities worldwide. The inaugural challenge offered 64 challenges and received 101 solutions. By 2014, it had expanded to events hosted in 95 cities with 671 solutions offered for the 40 presented challenges. Dozens of challenges supporting NASA's different mission directorates are available for participants to choose; the 2014 Space Apps Challenge divided challenges into five categories: technology in space, human space flight, asteroids, Earth watch, and robotics. Challenges were developed by collaboration with subject matter experts within NASA as well as the White House Climate Data Initiative, NOAA, and the EPA. The 2014 event generated considerable Internet traffic, with 29.5 million tweets recorded using the #SpaceApps hashtag for the event.[9]

The 2014 NASA OGP notes the creation and development of three new flagship initiatives between 2014 and 2016: the Climate Data Initiative, the Agency Information Architecture and Management project, and the Asteroid Grand Challenge. The Asteroid Grand Challenge seeks to "find all asteroid threats to human populations and know what to do about them." It is a broad, ambitious, multifaceted challenge requiring coordination with relevant groups within and outside of the government to include universities, amateur astronomers, and other stakeholders. The OGP states that NASA will be making use of "Public-Private Partnerships, Incentive Prizes, Crowdsourcing, and Citizen Science…to empower a broad cross-section of the general public to aid in addressing this threat…while enabling pieces of the problem to be addressed by individuals and organizations not specifically trained for asteroid tracking and characterization."

The agency has so far upheld the OGP's objectives. One notable partnership is that with SpaceGAMBIT, arranged via a Space Act Agreement to develop new ways for the public to participate in the Asteroid Grand Challenge. SpaceGAMBIT describes itself as "a US-government funded open-source space program." In November of 2014, it announced 10 new projects that include a browser game, an interactive space-based adventure, and software that streamlines the process of submitting astronomical sightings and discoveries to databases, social media feeds, and other Internet-based communal services.

The challenges presented by the OGP have led to many new initiatives for NASA. Limited by funding and political support for specific missions, the agency is led to seek out innovative methods of achieving its goals. Unconventional partnerships such as that with SpaceGAMBIT are becoming more common for NASA and there is growing evidence to support these as a prudent part of space policy. Partnering with the crowd in particular to conduct scientific research via citizen science projects can help NASA accomplish its goals with great efficiency, low cost, and even provide new solutions to difficult problems, all while engaging the public and fulfilling the requirements of the OGP. Reaching outside the agency for solutions has a wealth of benefits and only limited drawbacks.

NASA'S ADVANTAGE: THE PUBLIC

In a climate of persistent budget restraints and policy swings from one administration to the next, policy innovation for NASA is not just a check in the box for Open Government, but rather a necessity to achieve its time- and cost-sensitive missions with limited resources. Further development and expanded use of citizen science and crowdsourcing methods can provide NASA with unique benefits compared to traditional policy approaches and research methods. Whether soliciting innovative solutions from the public with the lure of prizes and grants or harnessing the power of volunteers to analyze large datasets, reaching out to the space-curious (though not necessarily professional) community can help the agency move forward. These space-curious individuals are a tremendous asset, making the successful evolution of citizen science project design and tactics for maximizing participation vital.

NASA is already particularly adept at reaching the public with the appeal of space via captivating photos from the Hubble Space Telescope and, more recently, a massive social media campaign around the Mars Science Laboratory *Curiosity* rover. NASA reported record Internet traffic figures at the time of the rover's suspenseful landing. When the agency was temporarily reduced to only 3% of its workforce during the 2013 shutdown, space aficionados began a #ThingsNASAMightTweet campaign. Over 15,000 tweets were made using the aforementioned hashtag, which led to 42.3 million impressions, or deliveries of tweets to accounts' Twitter streams. NASA's fans used the hashtag to discuss the Lunar Atmosphere and Dust Environment Explorer, the Lunar Reconnaissance Orbiter, the Juno spacecraft's Earth flyby, and other timely space events rather than criticizing the shutdown.[10]

NASA has also adopted the use of NASA Socials (formerly known as NASA Tweetups), during which the agency invites members of the public to NASA facilities to view launches, see the development of spacecraft, and meet scientists, engineers, astronauts, and managers while sharing their experiences on Twitter, Facebook, and Google+. For those who pass NASA's social media engagement criteria, these opportunities grant attendants the same access to events as traditional media representatives.[11] The Space Tweep Society is an active group of space enthusiasts on Twitter that organizes and disseminates information about space-related events for its members to attend and tweet the proceedings.

Despite minimal coverage from mainstream media outlets, NASA was able to generate substantial buzz around the Mars Science Laboratory *Curiosity* rover's landing in Gale Crater in summer 2012. In addition to a live stream of the tension in the Jet Propulsion Laboratory (JPL)'s *Curiosity* team during the "seven minutes of terror" (which also created Internet buzz around JPL's "Mohawk guy," Bobak Ferdowsi), NASA developed interactive "Be a Martian" virtual-reality browser and mobile apps and an augmented reality app providing a way to interact with the rover in 3D with an augmented reality target image.[12] Beyond the initial buzz, NASA's missions have maintained and even gathered greater interest. *Curiosity's* anthropomorphized Twitter account had 1.82 million followers as of February 2015,[13] twice what it claimed at the time of its landing.[14]

NASA had demonstrated that it has a massive fanbase and impressive social media prowess despite minimal media attention and the lack of ability to advertise. If leveraged properly, this could give the agency more power to achieve even more of its goals on a limited budget. Citizen science projects can heavily benefit from the agency's social media aptitude to increase public engagement and outreach and make NASA's work visible as "not just for rocket scientists," as it disseminates information on current space activities and allows the layperson to participate in a way that is (if designed correctly) digestible and approachable.

These projects have the capability to promote general scientific literacy and awareness of scientific research. The interactive nature of citizen science projects can also provide participants with a sense of ownership over the data, discoveries, and taxpayer-funded agency activities. In an age in which substantial gaps exist between the scientific consensus and American citizens on a wide range of issues, such as anthropogenic climate change, use of genetically modified organisms, and vaccinations,[15] it is increasingly important to act on increasing scientific literacy among the general public.

There is also a growing public sentiment that American leadership in science is falling behind. Pew Research Center found in early 2015 that 54% of Americans believe that U.S. scientific achievements are either the best in the world or above average when compared to other industrial countries, down 11 percentage points from 2009. Only 16% of AAAS scientists and 29% of the general public considered American science, technology, engineering, and math (STEM) education in grades K-12 to be best in the world or above average. The United States has a growing science problem and citizen science could be a viable tool for addressing it, particularly by engaging children in games.

NASA can leverage its social media following to increase scientific awareness and literacy, generate public enthusiasm and support for its missions, further research across all of the agency's disciplines, and increase the confidence of American citizens in their country's leadership role in scientific achievement. It can now also use the public much more directly by harnessing the power of crowds for research and put what is perhaps its greatest asset to work.

WHAT CAN BE GAINED FROM CITIZEN SCIENCE?

As a relatively new method of conducting scientific research, citizen science presents great potential. The primary benefits are derived from the use of "wise crowds" and the ability of volunteers to gather, categorize, and/or analyze data in much larger quantities than professional scientists would require without the help of a mass of volunteers. By engaging the public in scientific research, projects have the potential to increase scientific literacy and awareness of current areas of research. As citizen science becomes a more popular method for large-scale data analysis, it evolves, bringing data policy questions into the game. Although fears over the validity of data collected from volunteer crowds with limited to no scientific background are intuitive, they are generally overstated.

In his book, *The Wisdom of Crowds: Why the Many Are Smarter Than the Few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations*, James Surowiecki argues for better decision making via diverse groups of independently thinking individuals as opposed to isolated small groups of experts. Many of the arguments presented in *The Wisdom of Crowds* are applicable to citizen science projects, which make use of "wise crowds." Surowiecki defines the four characteristics of wise crowds, which distinguish them from irrational crowds, as follows[16]:

- Diversity of opinion (each person has private information, interpretation, analysis, and/or intuition)
- Independence (opinions not determined by those around them)
- Decentralization (specialization and influence from local knowledge)
- Aggregation (private judgments can be turned into collective decision)

The "wise crowds" of citizen science projects adhere to all of these characteristics. Online game-like portals such as Zooniverse's Planet Hunters do not discriminate against participants or have barriers beyond free account creation, and so individuals of any degree of experience and education may participate, conferring the benefits of having diverse backgrounds represented. Cognitive diversity is particularly valuable to projects relying upon collective intelligence as it allows for a greater number of approaches to a problem. Data is presented to participants in an isolated format through which they make and submit their decisions free from influences inside the system. The classifications are then visible to the project directors who have an aggregated data source from which to work. The "wise crowds" approach is also known as "collective intelligence," in which the collective measurements by a large group of volunteers are more likely to be correct than the subjective opinion of a single scientist.

Rebecca Mitchell and Stephen Nicholas deem cognitive diversity to be a factor that can contribute to new knowledge creation. Defining cognitive diversity as "the extent to which the group reflects differences in knowledge, including beliefs, preferences and perspectives," they hypothesize and demonstrate that a statistically significant link exists between cognitive diversity and the emergence of creative new knowledge in groups. By using groups with cognitive diversity, "institutional and task-related pressures" can be overcome as well as other factors inhibiting progression that may be a result of preexisting social relations in a more cognitively homogenous group.[17]

Relying entirely upon professional scientists to conduct research can lead toward detrimental results from "expert overconfidence," in which experts have an unrealistically high opinion of their own capabilities. Their judgment can be described as poorly calibrated, in which "calibration" is used to describe the level of agreement between the expert's estimates and reality. A Russo and Schoemaker study asked business managers to provide 90% confidence intervals for unknown quantities of interest, yet only 40–60% of the intervals contained the true value.[18]

The structure of Zooniverse's projects ensures that classification decisions are made simultaneously by its users rather than displaying other volunteers' classifications in sequence to prevent those currently analyzing a particular data set from altering their answers for the sake of conformity or out of self-doubt. This process avoids the "information cascade" phenomenon. When individuals are judged or rewarded based on their declared decision, they tend to follow a preexisting trend if a clear one exists rather than rely on their own judgment.[19] Individuals participating in these projects thus do not feel the need to conform if they come across anomalous data or make a classification contrary to the majority. This method helps to prevent the detrimental consequences of "groupthink" decision-making,[20] which can plague scientists, policy makers, and academia.[21] Citizen science projects designed in similar manners can thus subvert organizational biases.

Culturally, science is growing to be an increasingly collaborative field as specializations evolve and take precedence. Co-authorship has been increasing dramatically in recent years, as have articles with large (greater than 100) numbers of authors. The Large Hadron Collider at the European Organization for Nuclear Research has been responsible for numerous articles counting over 1,000 authors. In 2011, 44 physics articles were published with over 3,000 authors.[22] Collaboration in science has pushed beyond national borders to connect scientists worldwide. In addition to networks of scientists of different specialties, expansion of this collaboration to members of the public is a natural and approachable next step in the interconnectedness of scientific research.

Zooniverse hosts over 20 projects in the sciences and humanities that can be classified as *scientific discovery games*.[23] These games can be defined as the adaptation of computationally difficult scientific research questions into a game-like ("gamified") experience for players of any level of scientific exposure. The primary goal of all such games is to advance scientific research by enabling amateurs to do a large portion of the work. This unique goal has important implications for game design, which will be addressed in a later section. Volunteers participate in Zooniverse projects directly out of their Internet browser, generally classifying data in the form of photos or short videos. Each project has an accompanying discussion forum through which participants can converse about the project or any other topic.

Crowdsourced research makes massive amounts of data manageable for scientists and drastically reduces the time needed for tedious classifications and analysis. Galaxy Zoo, a Zooniverse project, launched in 2007 with the goal of using the public to classify the morphology of 1 million galaxies using data from the Hubble Space Telescope and the Sloan Digital Sky Survey. With each galactic feature requiring 20 unique volunteers to categorize for the sake of reliability, Galaxy Zoo's astronomers estimated it would take 3–5 years to hit the 1 million mark. The project instead reached its goal in three weeks. Galaxy Zoo provided scientists with over 50,000,000 individual classifications in the first year from 150,000 unique volunteers. According to Chris Lintott, a Galaxy Zoo co-founder, the crowd contributed the same number of classifications in the project's first 6 months as a graduate student working without breaks for 3–5 years would have.[24] Contributors to Moon Zoo, another Zooniverse project, have classified nearly 4 million images from NASA's *Lunar Reconnaissance Orbiter* since Moon Zoo's launch in 2009.

The research contributed to these programs from citizen science projects has not only accelerated research goals but also translates into significant financial benefits. Analyzing the seven projects started on Zooniverse in 2010 (Solar

Stormwatch, Galaxy Zoo Supernovae, Galaxy Zoo Hubble, Moon Zoo, Old Weather, The Milky Way Project, and Planet Hunters), Sauermann and Franzoni found that in the games' first 180 days, volunteers contributed a total of 129,540 hours of labor, ranging from about 1,890 hours for the smallest project to over 54,000 hours for the largest. When applying the typical hourly wage of an American undergraduate research assistant ($12.00 per hour, according to the authors), these contributions were valued from $22,717 for the smallest project to $654,130 for the largest, with an average of $222,068. The total contribution for the 180-day period was valued at $1,554,474.

These projects can also help to develop technology for machine learning by creating large training datasets from citizen science input. Humans are able to recognize patterns that an untrained machine could not, even if the humans are untrained. The resulting data can then be introduced to computers, increasing their ability to perform. With smarter machines working alongside humans, the scientific process can be made even faster. A hybrid approach allows for a balance between the strengths and weaknesses of humans and machines. The Milky Way Project asks participants to identify bubbles in infrared images from the Spitzer Space Telescope. In addition to its 35,000 citizen scientists, the project makes use of an algorithm called Brut to accomplish the same task with accuracy comparable to expert astronomers. In comparing data from the amateur volunteers, professional scientists, and the algorithm, the Milky Way Project astronomers can identify areas in which the volunteers are able to detect patterns that Brut cannot. This information is compiled into training data sets to increase the performance of the algorithm.[25]

While some of the data collection or classification techniques used in these projects could be run by computers, the "human touch" of volunteers allows serendipitous discoveries to be made. Hanny's Voorwerp is a quasar ionization echo, a very rare astronomical phenomenon, which was discovered in 2007 by Galaxy Zoo volunteer Hanny van Arkel, a Dutch schoolteacher with no background in astronomy.[26] A Neptune-like planet, designated "Planet Hunters 1" or PH1, was discovered and found to have a stable orbit existing in a four-star double-binary system by Planet Hunters volunteers in 2012. In addition to the discovery of the first planet existing in such a four-star system, the Planet Hunters team was able to obtain radial velocity measurements in addition to the transit information the site uses to detect planet candidates. The radial velocity measurements allowed for PH1 to be officially classified as a planet rather than a planet candidate.[27]

Foldit was designed by the University of Washington as an attempt to expand protein structure modeling and prediction by integrating human spatial reasoning and problem solving into their research. Greater understanding of a protein's function can be gathered once its structure is known[28]; thus, scientists sought out human volunteers, hoping their cognitive functions would accelerate the discovery process. Algorithms from the Rosetta structure prediction methodology were translated into a user-friendly format along with direct manipulation tools and given to Foldit players. The game attracted 57,000 players to compete to manipulate proteins into more efficient structures. When evaluating human performance, the authors noted that "unlike computational approaches, they explore not only the conformational space but also the space of possible search strategies." When comparing human predictions to Rosetta predictions in an array of 10 puzzles, Rosetta was "numerically better" than Foldit on 2 puzzles, similar on 3, and outperformed by Foldit on the remaining 5 (2 of which saw the players perform significantly better). Allowing Foldit players to codify their strategies resulted in the creation of a wide diversity of folding algorithms. These algorithms can be shared with others and even evolve in a social fashion, where popular "recipes" are copied and customized.[29]

Cooper *et al.*[23] noted that one shortcoming in human performance was notable when dealing with an extended protein chain in a difficult set of puzzles. Players had difficulty reaching the native conformation with this unfolded chain, suggesting that players are better at finding errors in partially correct models than dealing with a "blank slate." Provided the complexity of the game is not excessive, this suggests that gamifying scientific research into a user-friendly format could provide creativity of results in addition to simply processing large amounts of data. Although protein folding is not an inherently simple topic, researchers were able to bring in players with no experience in molecular biology by engaging them with introductory tutorial levels that introduce the participants to the game objectives and strategies.

It is still vitally important to hold data derived from citizen science volunteers to the same rigorous standards as that of professional scientists in order to ensure quality in results as well as to establish citizen science as a legitimate method of undertaking scientific research. Good project design will have each data set analyzed by a sufficiently large number of volunteers to reduce error with outliers or other noteworthy classifications also examined by trained research scientists. The research scientists must determine what indicators, categories, or other research factors are most significant to the project and make sure any technology used supports the goal and does not distort the data on either end of the transaction or at any other point in the process.

There is ultimately a limit to the complexity of activities a project can request of its volunteers. While a highly complex research subject such as quantum mechanics might be difficult to condense to a layman-friendly citizen science game, these limits come from the game itself rather than the topic being studied. Attracting and retaining volunteers is of substantial concern. The project must be palatable enough to a general audience to catch their curiosity, not excessively complex as to lose volunteers, and rewarding enough to ensure continued participation.

Participation frequency and magnitude in citizen science games have been shown to generally be heavily imbalanced. In Sauermann and Franzoni's analysis of Zooniverse projects launched in 2010, the top 10% of all contributors accounted for between 71% and 88% across all projects with an average of 79%. Research is needed to evaluate the inequality in contributions and determining what makes a volunteer return.

The complexity of the project can also affect accuracy depending on the age and education levels of those involved. Delaney *et al.* assigned 1,000 volunteers an assessment of the species and sex of invasive and native crabs within seven coastal states in the United States.[30] Third-grade students were able to report with 80% accuracy, while students in seventh-grade reported a 95% accuracy; 80% of seventh-grade students were able to determine the sex of the crabs, while students with at least 2 years of university education reached a 95% accuracy rating. However, while Delaney *et al.* hypothesized that certain thresholds of education level are necessary for different degrees of accuracy, it is possible that age-related cognitive development is as much or more of an influence compared to education. Increasing complexity in project goals would likely require greater follow-up analysis by the primary research team. Planet Hunters volunteers were able to identify some planet candidates that computer algorithms were unable to flag.

Astronomy and other space sciences, due to their primarily observational nature, have a particular drawback limiting the extent to which projects can be interactive. Compared to environmental sciences, for example, would-be citizen scientists are unable to participate in field activities and develop social leadership and mobilization skills or form a local network that could turn volunteers into full-fledged activists and advocates. In time, development and refinement of virtual and augmented reality systems could provide volunteers with a more tangible grasp of their subject, but space projects do not get to easily reap the benefit of connecting local groups of enthusiasts with one another.

Use of citizen-generated data as a new practice is likely to bring about a new set of policy issues. Citizen science is not a one-size-fits-all endeavor; as such, data policy concerns differ based on the level of involvement in the research process, data types collected, the methodology of data collection, and the organizational structure of the project.[31] Volunteer data protection and other data-related policy issues might come into play, particularly if a situation arises that showcases the lack of existing policies to ensure participants' privacy and the project's data security. Data policy provides guidelines for how the project and research team can interact with a citizen science participant, contained in user agreements, terms of use, legal policies, and/or privacy policies. Intellectual property issues might arise depending on the nature of the citizen science project.

A report released by the Wilson Center Commons Lab, *Typology of Citizen Science Projects from an Intellectual Property Perspective*, sorts citizen science projects into four broad categories based on the type of participation involved: classification or transcription of data; data gathering; participation as a research subject; and/or the solving of problems, sharing of ideas, or manipulation of data. Intellectual property concerns are unlikely to emerge in the first three categories, although some copyright issues might be relevant when input is in the form of photographs, videos, and written observations. When citizen scientists are more directly involved in problem solving and data manipulation, their contributions "may rise to the level of inventorship or authorship," at which point intellectual property rights must be considered. Scientists concerned about intellectual property need to consider two key questions:

- "Are the contributions that are being sought from the public ones in which participants may have intellectual property rights?"
- "Is the public participation of a kind which may give some participants intellectual property rights in the research output?"

If this form of participation is to be expected or posited in a particular citizen science project, the report advises that any potential intellectual property concern be addressed early in the project's lifecycle, specifically when writing the terms of use.[32]

When evaluating potential uses of citizen science for NASA's research goals, it is important to determine what sort of actions the volunteers will be taking. Using the four-pronged division identified by Scassa and Chung for the Wilson Center, classification-type projects are currently the most common type of citizen science used for space-related research. Participants are often asked to observe or classify images or short videos taken by telescopes and other spacecraft. The photography-heavy element of astronomy lends itself well to these projects and it is often reasonable to expect untrained scientists to be able to recognize patterns, anomalies, and other distinctive features when given a brief tutorial. Although data gathering activities are not viable for anyone incapable of arranging for transportation to the International Space Station or beyond, NASA can make use of more hands-on projects in its Earth science programs.

Using volunteers as research subjects or tasking them with problem solving or data manipulation is not the most intuitive methodology, but it may behoove NASA to look into different methods of user contributions, particularly if seeking to extend citizen science to the Human Exploration and Operations Mission Directorate (HEOMD) and other nonobservational facets of space research. Although the technology is still relatively early in development, citizen science games could be extended to the Oculus Rift or other virtual reality platforms that could open up participants to be research subjects. Immersive simulation technologies such as these could prove particularly valuable in assessing human brain function and other physical or psychological responses to spaceflight-related stimuli.

The classification-style citizen science games are not limited to astronomy and planetary science when researching space. The biomedical field has also been embracing the use of citizen science projects; NASA should tap into their expertise and extend the use of citizen science to accomplishing its goals of the Human Research Roadmap where possible. As an example, NASA can crowdsource research on the effects of spaceflight on human DNA by having volunteers analyze data from astronauts. Citizen scientists could also evaluate potential landing sites on Mars for future missions using data from the active rovers and the *Mars Reconnaissance Orbiter*. Provided the tasks expected of volunteers are kept to reasonable degrees of complexity with concise and well-articulated training, there are few facets of NASA's research goals for which citizen science cannot make valuable contributions.

GAME AND PROJECT DESIGN CONSIDERATIONS

Perhaps the greatest existing opportunity gap that could be exploited for higher levels of participation lies with the expansion of citizen science projects to mobile gaming apps. Technology usage trends in the United States indicate a strongly increasing prevalence and use of mobile apps, which poses a great opportunity for groups capable of creating an engaging app for citizen science. Mobile devices were responsible for 55% of American Internet usage in January 2014, the first time mobile devices have overtaken PC Internet traffic. Mobile apps alone were responsible for 47% of all Internet traffic.[33] These trends indicate that the relative increase for mobile Internet usage (and therefore mobile app usage) will continue, as smartphone adoption increases and desktop PC sales dwindle. Although the decline in PC sales is not as sharp as in recent years, smartphones and tablets still threaten industry growth.[34]

American Android and iPhone users over the age of 18 spend 65% more time per month using apps than they did 2 years ago, with an average of 30.25 hours per month spent on phone apps and an average of 26.8 apps in use per month per person. Entertainment apps saw a 71% growth between Q4 of 2012 and 2013, the second highest category behind photography.[35] When it comes to time spent solely on apps, gaming consumes 32% of time spent on iOS and Android devices.[36]

Despite their rampant popularity in the general population, apps have generally not been adopted yet as a major platform for game-like citizen science, but the concept has been tested with success. Kretser *et al.* pointed to a pilot app in China used for identification of illegally traded wildlife and wildlife products as demonstrating "high potential" for future use of mobile app crowdsourced technology in their work.[37] Users of the free *Wildlife Guardian* app in China indicated positive feelings overall in a Wildlife Conservation Society survey; 60% of users considered the app "very valuable" and another 25% ranked it "valuable" for wildlife conservation; 70% of police officers surveyed ranked the app as "very useful" for supporting their specific work or activities, with the remaining 30% responding that the app was "useful."

Cancer Research UK has developed two free mobile game apps that use citizen science to aid in research. *Play to Cure: Genes in Space* arose as a response to a large backlog of genetic breast cancer data. Analysis of the patterns in this data could help to discover potential new treatments, but there was so much data that it would take scientists an impractical amount of time to process it. Cancer Research UK partnered with independent game studio Guerrilla Tea, whose team of seven developers took five months to bring the scientists' goal to life.

Play to Cure tasks gamers with marking spaceship routes to collect the maximum amount of "Element Alpha," which is in reality cancer DNA microarray data with varying patterns and deviations (as seen below). Upon collecting the substance and trading it in (at varying exchange rates) for experience, players can level up and earn new titles and ship components. Each "route" is analyzed multiple times by different participants before the classified patterns are returned to the scientists. The scientists are then able to identify common genetic abnormalities among cancer patients significantly faster.

Play to Cure was released in February of 2014. By March, its users had already made 1.5 classifications of genetic data, which would have taken scientists 6 months to analyze. In a more tangible metric, within 1 month, citizen scientists had analyzed approximately 40 miles of DNA data.[38] Professor Carlos Caldas, senior group leader at the Cancer Research UK Cambridge Institute, noted that in addition to the boost in research and analysis provided by gamers, "computers can't analyze our research data with 100 percent accuracy—we need the human eye for greater precision."[39]

In designing *Play to Cure*, Guerilla Tea purposefully kept the game's purpose (genetic data analysis) entirely distinct from the gameplay environment and experience (spaceflight). They sought to make the game action-oriented and fast-paced and added an asteroid field section in which players need to either quickly navigate around asteroids or shoot them to avoid damaging the ship and Element Alpha cargo, which created a sense of a threat to the player. Player progression and customization were also important characteristics to give players goals to work toward and a sense of ownership. When released to the public, *Play to Cure* was ultimately reviewed as a game more so than a citizen science project, which brings attention to the challenges brought about by restrictions on gameplay design necessitated by keeping the scientific process and data integrity unimpeded.[40]

After *Play to Cure*'s successful launch, Cancer Research UK developed another app, a puzzle game this time, to crowdsource more research. *Reverse the Odds* is a two-part game split between analysis of magnified pretreatment tissue from former cancer patients and a puzzle section used to advance the "plot." The analysis is simple, with the game only asking players whether they can identify anomalous cells, what percentage of the anomalous cells are blue, and how bright the blue cells are. Each completed analysis grants the player a potion, which they can use to activate the puzzle section of the game. The game's name, *Reverse the Odds*, comes from this Reversi-like mini-game phase, which has alternating win conditions. Players are rewarded with more puzzle-unlocking potions as well as other beneficial potions if their results are consistent with others' findings. The player's level is indicated on the main screen and a running count of total slides analyzed worldwide is visible on loading screens.[41]

Gamification, although lacking a single broadly accepted definition, is effectively the process of employing game thinking and mechanics to nongame problems or applications to engage users to accomplish goals. Gamified tasks centralize the user as the player around which the experience is designed, taking into account user motivation and interests. User motives can include socialization, competition, learning, contribution, and a sense of achievement, all of which are uniquely important or unimportant to any given user. Gamification provides rewards (*e.g.*, badges, level progression, leaderboard placement, and virtual currency) or other metrics for accomplishing tasks and reaching milestones. Citizen science can take advantage of gamification by using game elements to motivate participants to achieve personal goals that are aligned with the organization's goals.

In designing scientific discovery games, Cooper *et al.*[23] identify three necessary aspects to be taken into consideration to maximize the benefits of using humans rather than computer algorithms. First, the graphics and visualization need to accurately display the information to be analyzed while not overwhelming a novice to the game. Second, there need to be some allowances made for human creativity and exploration while still respecting scientific constraints. Lastly, scoring needs to accommodate multiple human strategies while staying true to the current models. These projects often seek to explore the unknown and reveal information about natural phenomena and unexpected discoveries can be made. Due to the difficulties of attempting to design a game around so many unknown factors and yet-to-be-discovered goals, scientific discovery games present unique challenges for game designers and researchers.

Mobile gameplay in particular differs from PC or console gaming in that users play in short spurts rather than drawn-out sessions. Mobile games must therefore be able to deliver a brief, accessible, and satisfying experience while still giving the player incentive to return to the game later. *Play to Cure* follows this model, in which the primary "action" aspect of the game, collecting Element Alpha, lasts under a minute for each data analysis (unless the user is tasked with escaping an asteroid field, adding a comparable amount of action gameplay). The rest of the game time is spent upgrading and customizing the player's spaceship, providing plenty of convenient timeframes to exit the game if necessary.

In adapting scientific data analysis to game format, it is crucial to make sure the data is not distorted in either direction between researchers and players. However, if game designers seek to involve an audience that is perhaps less motivated by contribution to scientific research alone than that of projects in the vein of Galaxy Zoo, the entertainment value must also be considered. If citizen science project creators wish to take advantage of the popularity of mobile gaming or continue to use game-like elements in their browser applications, it is worth their time to consider the mechanisms most likely to attract and retain the greatest number of volunteers while maintaining the integrity of their data.

Old Weather, launched in October 2010, is a Zooniverse project in collaboration with NARA and NOAA that asks participants to read handwritten pages of 19th-century ship logs and transcribe passages pertaining to weather with the goal of digitizing the data and modeling climate, in addition to aiding historians with research. The project team added a ranking system to engage participants, starting new volunteers at "Cadet" ranking when they "join a ship." Upon completion of 30 weather observations, participants receive a promotion to "Lieutenant" with a competitive system for the most active transcribers to then become "Captain," a position that can be lost if another volunteer's transcriptions outnumber the incumbent's. Thousands of *Old Weather* participants transcribed over 1 million ship logbooks.

However, while the gamification motivated some of the most active volunteers of *Old Weather*, it either had no effect on some of the casual participants or was a direct influence in some participants' decisions to end their participation. These findings suggest that a balanced approach to gamification would be desirable in attracting those motivated by the competitive system while not discouraging those who dislike such a system.

Successful game design, then, is crucial to making a gamified citizen science project rewarding and engaging to the maximum number of people. While some participants might be strongly motivated by competitive game elements, others who prefer a heavily cooperative approach might be put off by a competitive design to the point of avoidance.

Eveleigh *et al*. suggest the following design considerations:

- Scoring mechanisms should provide personal milestone targets alongside competitive incentives.
- Personalized feedback and the ability for participants to review their contributions and learn from mistakes would encourage quality over quantity.
- Schedule challenges and/or prize drawings, perhaps for teams rather than individuals, as a way to keep or reinvigorate interest.
- Take advantage of narrative appeal, providing a logical path for participants. This can encourage the compulsion to finish, for example, a particular section of a Martian map.[42]

Allowing players access to their detailed personal statistics in addition to those of the entire community could provide an easy method of viewing their achievements in a quantifiable form and give the more competitive players a frame of reference as to their current relative standing. A running total of classifications made and other notable achievements (planets confirmed, for example) could also help create a sense of community progression and achievement.

Giving top participants visible recognition with special icons in community forums could provide an easy, cheap "badge" to display. Applying such a mechanic to high-ranking volunteers for a variety of accomplishments such as having high accuracy rates, large quantities of data analyzed, length of service, and providing helpful tips to others could encourage participation for volunteers of all playstyles.

A clear goal for a project must exist during the planning phase and be supported through the entirety of its life cycle. Does the game seek to educate, entertain, or simply serve as a method for the public to participate in scientific research? If a secondary intent of the game is to educate, additional considerations come into play, such as the potential hindrance to performance that can accompany hint systems.[43] Some research has been done on various mechanisms used in educational games and their benefits and drawbacks.

Developers also need to know their target audience and determine how to best appeal to them to build a user base from the ground up or make use of existing human resources. A project developed with frequent museum visitors in mind, for example, might want to consider making a game more casual compared to a game aimed toward people who seek out citizen science projects independently.

Some lessons can be learned by examining highly successful casual games. PopCap is a game studio that has mastered the genre with major titles, including *Plants vs. Zombies* and *Bejeweled*. When adding features, according to Ed Allard, PopCap's vice president of development studios, the game studio carefully considers whether the potential feature would turn any particular demographic away from the game. While many popular apps, such as Instagram, achieve their fame on one platform first (iOS, in this case) and then spread to others by popular demand, their approach is not necessarily the best practice for researchers hoping to reach as wide of an audience as possible as quickly as possible. Small audio–visual cues tied to analysis completions or mini-game successes could provide positive feedback for the players.[44]

This system of positive reinforcement, combined with the natural human urge to seek out patterns, has made games such as *Candy Crush Saga* hugely popular. *Candy Crush Saga* reached 500 million downloads in November 2013, just one year after its port to mobile platforms in November 2012.[45] As of February 2014, the game boasted 93 million daily users.[46] Its success can be attributed in part to a "disproportionate feedback," a cycle of pleasurable stimuli involving colors, sounds, and words such as "delicious," which immediately reward the player, a mechanic also found in slot machines.[47] While citizen science games should not endeavor to become disruptively addicting, introducing pleasant sound or color cues where appropriate could be an asset in encouraging players to return to the game.

Many successful games utilize a system where players earn virtual currency or unlock new abilities as they play. These systems are likely undesirable for citizen science due to the need for all participants to contribute as effectively as possible from the start; however, *Play to Cure* uses such features with success by integrating them in the more action-heavy elements that do not detract from the analysis itself, which is done independently. Esthetic bonuses give players goals that do not require start-of-game reduced research efficacy.

Another possible pitfall of the research game design process is having players focus in on their personal game results rather than data validity. To avoid a drop in accuracy from hyper-competitive players, designers can tether progression to quality of results so that players are required to perform well and play often to increase in standing.

Where many mobile apps charge users for an initial download, it is important that research apps remain free. Players are providing a free service to the researchers, thus selling the app to the user would reduce the user base and the amount of research returned. Provided the end goal is maximum quantity and quality of data returned to the researchers, reaching a broad audience is vital and increases the chance of viral success. A broad audience further increases demographic diversity, providing a range of skill sets that will favor different types of crowdsourced research.

OTHER TYPES OF CROWDSOURCED RESEARCH

During the height of European expansion across the seas, transoceanic navigators were able to determine latitude with the height of the sun at noon, but longitude was not so easily discernable. Eager to gain every advantage for the spread of their empires, European governments offered increasingly competitive prizes in search of a solution to this problem. The King of Spain advertised 1,000 crowns for the feat in 1598, followed by a raise to 10,000 florins by the States General of the Netherlands.[48] Scientists such as Giovanni Cassini, Christiaan Huygens, Edmond Halley, and Sir Isaac Newton had all attempted to solve the problem yet failed at finding a suitable method. A solution finally came about via the Longitude Prize, which was established by the British government in 1714. The winner, John Harrison, succeeded decades later in 1761. His invention of the marine chronometer won him £20,000 and resulted in a greatly increased level of safety in transoceanic travel.

Prizes and challenges require a high level of participation from those involved but can also come with the highest payoff for both entrants and sponsoring organization. Contests are ideal for situations in which the best approach is unknown, as they act as a set of diverse and independent experiments. These competitions are effective for complex, new problems that can benefit from experimentation and creativity, as well as those that require the development of a new technology or innovative use of existing technology. Prizes and challenges are meant to complement market incentives to catalyze innovation rather than replacing them entirely. NASA has made use of competitions to include the Space Technology Mission Directorate's Centennial Challenges, the Harvard-partnered NASA Tournament Lab, and the 48-hour, massively collaborative International Space Apps Challenge.

Prizes and challenges have made up the bulk of NASA's citizen science efforts since the enactment of the Centennial Challenge program in 2005, facilitated by executive mandate. The Stevenson-Wydler Technology Innovation Act of 1980 was signed into law by President Jimmy Carter with the goal of enabling federal laboratories to transfer technology to organizations outside of the federal government. The act gave federal agencies the authority to "enter into cooperative research and development agreements…with other Federal agencies; units of State or local government; industrial organizations (including corporations, partnerships, and limited partnerships, and industrial development organizations); public and private foundations; nonprofit organizations (including universities); or other persons."

The America COMPETES Reauthorization Act of 2010 was signed by President Obama on January 4, 2011, building off of the Stevenson-Wydler Act to specifically encourage the use of prizes and contests in federal agencies. In March 2010, the Office of Management and Budget released a memo titled "Guidance on the Use of Challenges and Prizes to Promote Open Government," providing a formal policy framework for the use of prizes and challenges as policy tools and openly encouraging their use. The COMPETES Act recognizes NASA's historic role in promoting innovation and suggests that NASA "allow full participation in any interagency efforts to promote innovation and economic competitiveness."[49]

The number of challenges and prizes has increased steadily since the enactment of the COMPETES Act, with 7 prizes conducted in its inaugural year, 27 in fiscal year (FY) 2012, and 41 in FY 2013 across 17 agencies under COMPETES authority. A total of 87 prizes under 25 agencies were reported under all prize authorities to include COMPETES in FY 2013. The U.S. Department of Health and Human Services was the federal leader in prizes under COMPETES authority in FY 2013, offering over $1,200,000 in total prize purses with an average over $46,000 a prize.

In FY 2013, federal agencies increasingly investigated how to ensure that successes from prizes continue to ripple throughout their missions after the conclusion of a competition. Some of the methods identified by a report from the Office of Science and Technology Policy (OSTP) included: "integration into an agency's existing research and development pipeline; targeting the solutions for scaled development or further development through other funding mechanisms such as grants or Small Business Innovation Research funding; forming partnerships to promote or deploy winning solutions; and tying an agency's future strategic plan to the lessons learned during the competition."

The report highlights the U.S. Department of Housing and Urban Development (HUD)'s Rebuild by Design competition, which sought solutions to help recovery efforts in the areas affected by Hurricane Sandy. The multistage competition had a $2,000,000 prize purse funded by HUD's philanthropic partners, led by the Rockefeller Foundation. The design teams are also incentivized with the prospect of involvement with the development and implementation of their solutions. According to OSTP, the time and resources contributed by the 10 finalists greatly outweigh the value of the prize purse.[50]

There is currently no central body at NASA that oversees citizen science; rather, their use has emerged organically among varying divisions. The Office of the Chief Technologist (OCT) employs contests in coordination with NASA's Centers, Mission Directorates, and external stakeholders. NASA Solve is a website created as the agency's "gateway" to prize and challenge opportunities. NASA initially created the Participatory Exploration Office (PEO) to address citizen engagement in the research process, but the office was short-lived.[51]

The NASA Center of Excellence for Collaborative Innovation (COECI) is a virtual Center founded in November of 2011 to address open innovation challenges. Housed under HEOMD, CEOCI works to assist NASA and other government entities with their development, execution, and postmortem evaluation of these challenges and prizes. Its focuses are trifold, specifically: first, advising government agencies on different methodologies and best practices; second, implementation guidance regarding infrastructure and the provision of appropriate platforms; and, third, measurement of impact and performance. The metrics are still an area that have not yet been explored in depth and more empirical data is needed.[52] COECI has successfully helped a number of other federal agencies navigate the challenge-making process. Some of the agencies assisted include Centers for Medicare and Medicaid Services (CMS), the Office of Personnel Management (OPM), U.S. Agency for International Development (USAID), Department of Energy (DOE), and the EPA.[53]

As awards are based purely on achievements rather than ongoing work, competitions can be a highly cost-effective method of seeking solutions to challenges. As opposed to traditional contract-based procurement processes, offering prizes allows the agency to see a multitude of results rather than attempting to judge before commencement of the project which competitor has the highest likelihood of success. Competitions can also provide more diversity in responses than traditional procurement methods as the removal of barriers such as the requirement for past performance demonstrations and ability to maneuver the federal procurement system broaden the pool of applicants to anyone with an idea. Challenges do not incentivize the risk-adverse as government contracting tends to do, leading competitors to take more risks on their own, none of which are undertaken by the government.[54]

Research from the Harvard Business School indicates that breakthrough solutions are most likely to come from either those outside the target scientific field or at the intersection of two disciplines.[55] John Harrison's Longitude Prize–winning solution was not astronomical, but a mechanical timepiece.

Ken Davidian of the Federal Aviation Administration (FAA) analyzed NASA prize competitions to identify best practices and lessons learned for development and design. His findings are summarized below:

- Simple, transparent, objective, and unbiased challenges are preferable to complex challenges that require expensive verification methods and/or qualitative judging.
- Challenges that show capabilities relevance to NASA programs are ideal.
- A balance in difficulty should be sought to avoid challenges that are either too easy or hard.
- Challenges that demonstrate capabilities that are applicable to future NASA programs, other aspects of the aerospace market, or Earth applications with near-term economic opportunities for the participants are historically the most successful.
- If potential competitors and/or sponsors of competing teams or potential co-sponsors of the prize purse show interest in the competition, this is a good indication of a desirable challenge.
- The most successful challenges generate excitement among the public, media, and educators, which further encourages more teams to participate.

Some corporations have also discovered the value in prize-driven innovation. The Google Lunar XPRIZE offers a $20 million grand prize for any private team (having no more than 10% in government funding) that can land a robot safely on the Moon, move it 500 meters on, above, or below the lunar surface, and send back high-definition video before December 31, 2016. Additional "milestone" prizes were awarded for demonstration of landing systems, mobility, and imagery. Five teams succeeded in achieving one or more of these, with Pittsburgh-based Astrobotic Technology, Inc., claiming victory in all three categories. A total of $6 million was awarded between the teams for achieving these milestones.

Volunteer distributed computing (VDC) allows participants to donate processing power to projects of their choosing at only the cost of increased power consumption and decreased PC performance. The participants connect to the project via a downloaded client (such as BOINC), through which project servers generate tasks, distribute them to participant computers, and return the results. New tasks are sent to participants upon completion. Distributed computing is an entirely passive form of contributing to projects and requires no analysis or evaluation on the participants' ends.

The first instance of volunteer-distributed computing began in January 1996 with the Great Internet Mersenne Prime Search (GIMPS), which is still operational and in November 2014 confirmed the discovery of the 44th Mersenne prime. GIMPS offers a prize of $3,000 for the discovery of new Mersenne primes having fewer than 100 million decimal digits and a $50,000 prize for the first prime having at least 100 million decimal digits. GIMPS estimates that the 100 million digit award may take 12–15 years of calculations before a qualifying discovery is made.

Distributed computing has been most popularized by SETI@home and Folding@home, which have attracted considerable numbers of volunteers each for their endeavors (analyzing radio signals for extraterrestrial intelligence and simulation of protein folding, respectively). SETI@home boasted over 6 million participants across the world as of 2011. The Folding@home lab has published 114 scientific research articles since the project's launch in October 2000.[56]

VDC has been further enabled by Berkeley Open Infrastructure for Network Computing (BOINC), a middleware platform used by SETI@home and around 70 additional projects. Half of BOINC participants are outside of the United States and the platform supports up to 30 languages, according to its founder and architect, Dr. David Anderson.[57] Opportunities for advancement exist beyond the personal computer; David Toth argues that video game consoles have become considerably powerful computing machines over the past 30 years and should be utilized in volunteer computing as well. Folding@home used the PlayStation 3 gaming console from March 2007 until November 2012, taking advantage of the console's computational efficiency. BOINC is now also available for smartphones, running processes over a wireless connection when the phone is plugged in and not in use.

While any person capable of setting up a client and connecting to his or her chosen project(s) on his or her personal computer can contribute to these projects, this less active role perhaps does not encourage participants to develop a sense of personal ownership in their participation. For those interested in science who do not have time to regularly participate in more active projects, however, VDC provides an easy method of contribution that is not subject to human error on the part of the user. It carries the additional advantage of not having its complexity limited by the abilities of a lay audience; rather, it is only inhibited by the extent to which developers can program the computations to be done.

Direct data sharing, perhaps more commonly known as "open data," allows members of the public to take data directly from the federal government to manipulate and analyze independently. Government-sponsored "civic hackathons" are rising in popularity, which typically encourage users to work toward a given goal with open data in a set amount of time. Out of the various methods of utilizing the public in scientific research, providing open data for "do-it-yourself" analysis is the most demanding of its users' existing capabilities and least demanding of design considerations. Code.NASA.gov makes open source data available to any who wish to independently interpret it.

The growing variety in citizen science opportunities available to interested volunteers of all degrees of knowledge, experience, and participation is helping to broaden the number of potential participants in crowdsourced research efforts. Each of these attracts a certain demographic, each of which should be studied in more depth to determine how to best maximize benefits derived from projects and the potential for reaching more participants. The following section addresses citizen science games, both with a review of previous demographic research as well as a new exploratory survey into the potential for expansion beyond browser apps to mobile apps.

WHO ARE THE CITIZEN SCIENTISTS?

Raddick *et al.* conducted a survey of over 11,000 Galaxy Zoo participants to analyze the overall demographics of its user base.[58] This research found that Galaxy Zoo participants are overwhelmingly middle-aged males; 82% of respondents to the gender question self-reported as male and the men outnumbered the women across all age groups. An excess of men between the ages of 50 and 65 was found relative to the U.S. online population, a demographic similar to that found in amateur astronomy.[59] The mean age was found to be 43 years with a standard deviation of 14.58 years. Galaxy Zoo volunteers are primarily American but with a substantial participant base existing in the United Kingdom. The users are also significantly more educated than the general online population.

In addition to demographics, the survey also investigated the motivations of participants. Twelve motivations for participation were identified in their previous research with use of grounded theory listed as follows: contribution, learning, discovery, community, teaching, beauty, fun, vastness, helping, zoo, astronomy, and science.[58] These were then presented to the volunteers in the demographic survey to be ranked. The clearly dominant motivation category chosen by those surveyed was the desire to contribute to scientific research, chosen by 40% of respondents. No other motivation category exceeded 13% of responses. The study found that these motivations occurred in common pairings (illustrated in *Fig. 1*):

- "Contribution" was associated with a high "science" ranking.
- "Help" was associated with a high "discover" ranking.
- "Astronomy" was associated with a high "science" and "learning" ranking.
- "Beauty" was associated with a high "contribution" ranking.
- "Fun" was associated with a high "contribution" ranking.
- "Learning" was associated with a high "teaching" ranking.
- "Teaching" was associated with a high "astronomy" ranking.

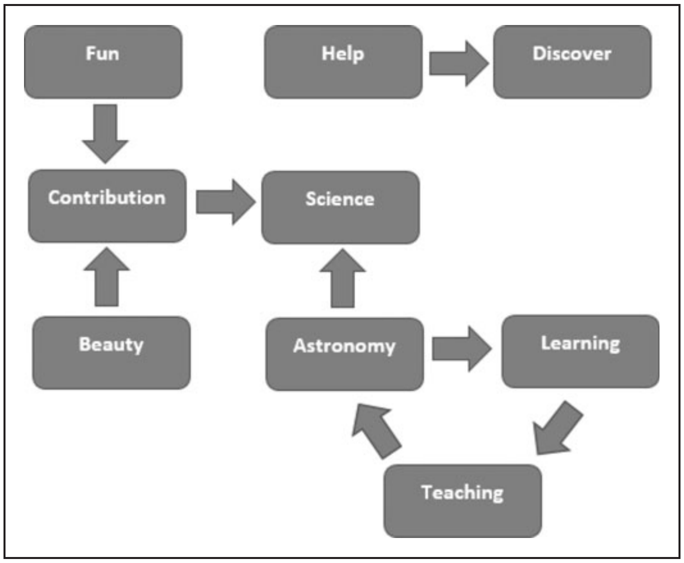

Fig. 1. Motivation relationship visualization.

These motivational pairings could provide valuable insight for project and game design. When considering the target audience and their primary motivations, secondary motivations could enhance user experience and guide developers in adding complexity and additional features appropriately.

The overwhelming representation of middle-aged males among survey respondents suggests that these projects are falling short in recruiting women in particular. Astronomy has traditionally been heavily male dominated. The American Institute for Physics conducted a survey of physics degree-granting departments in 2010 and found that women account for only 14% of faculty members in physics departments and 19% of faculty members in astronomy-only departments.[60] Recent research in game science shows that video game players are fairly diverse in age and gender, with women accounting for 47% of players and age distributions being evenly split between children under 18, young adults aged 18–35, and adults over 35. While apps focused on astronomy will likely have a user base biased toward men, a game that is reputably entertaining with widespread appeal could reach a wider audience.

For this research, I set out to investigate whether the availability of a mobile app version of space-related Zooniverse projects would increase the participation levels of the current computer-based participants. I distributed an online survey via each individual discussion board for Galaxy Zoo, Moon Zoo, Solar Stormwatch, Planet Hunters, The Milky Way Project, Planet Four, Radio Galaxy Zoo, Disk Detective, Sunspotter, and Asteroid Zoo as well as on the citizen science discussion area on reddit.com. The survey was distributed twice: first on December 18, 2014, and again on January 24, 2015. Results were downloaded on February 2, 2015, and thus no responses after that date were included in the analysis. No incentive was provided for taking the survey and it passed institutional research board approval at the George Washington University. Twenty-six participants from these projects responded. Three of the responses had partial completion with the omission of one response in each instance and have been removed from their respective analyses.

The survey contained minimal demographic questioning due to the extensive Raddick *et al.* study demonstrating a thorough overview of Galaxy Zoo demographics, which can be reasonably extrapolated to other Zooniverse space projects. Participants were asked for age, education level, and involvement in science academically or professionally. Questions asking participants to evaluate statements with responses, including "N/A," "strongly disagree," "disagree," "neutral," "agree," and "strongly agree," had these answer options converted to a Likert scale from 1 to 5, respectively, with "N/A" responses omitted. Statistical analyses were performed in R and Microsoft Excel.

Due to the primary advertisement method of this survey being the discussion forums for the respective projects, selection bias is likely to influence the responses, skewed toward participants who are already more active and engaged than the average user. When asked about frequency of participation, 84% of respondents indicated that they contribute to Zooniverse projects at least once a week, with 38% participating daily (*Fig. 2*). Distribution via project-wide mailing list such as the Raddick Galaxy Zoo survey would provide a larger sample size and better representation of Zooniverse participants.

Over half of the participants who responded to the survey were 30 years old or younger (*Fig. 3*). Only two (8%) of respondents listed high school as their highest level of education completed (one of which was the sole respondent self-reporting in the 0–18 age range), which is in line with the Raddick demographic survey suggesting that citizen scientists are generally more highly educated than the general population (*Fig. 4*).

Table 1 contains the average sentiment value for questions pertaining to interest in space sciences before and after Zooniverse participation, citizen science evangelism, interest in mobile apps as a platform for citizen science, current motivation levels for participation, and whether that would change with the availability of a mobile app. With 3 indicating "neutral," all of the average sentiment values indicate

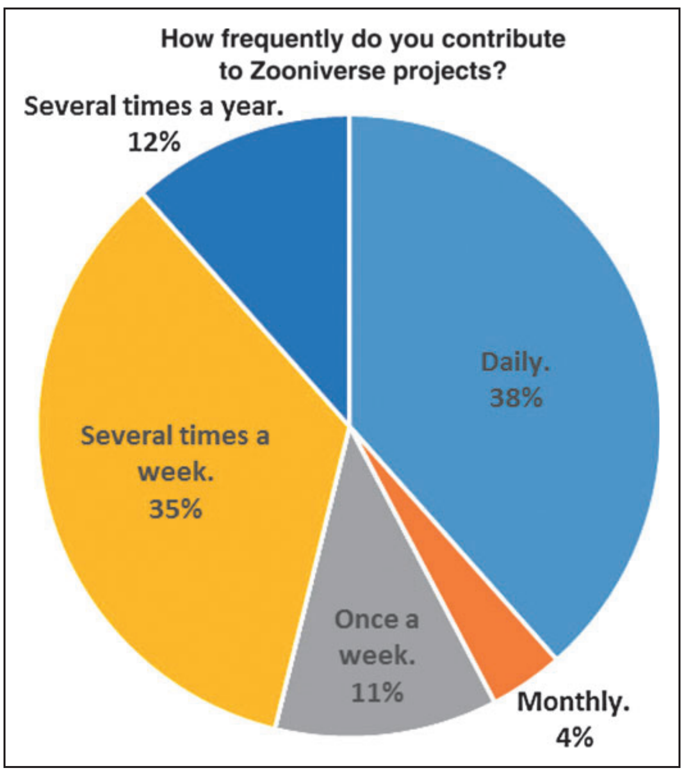

Fig. 2. Frequency of contribution to Zooniverse.

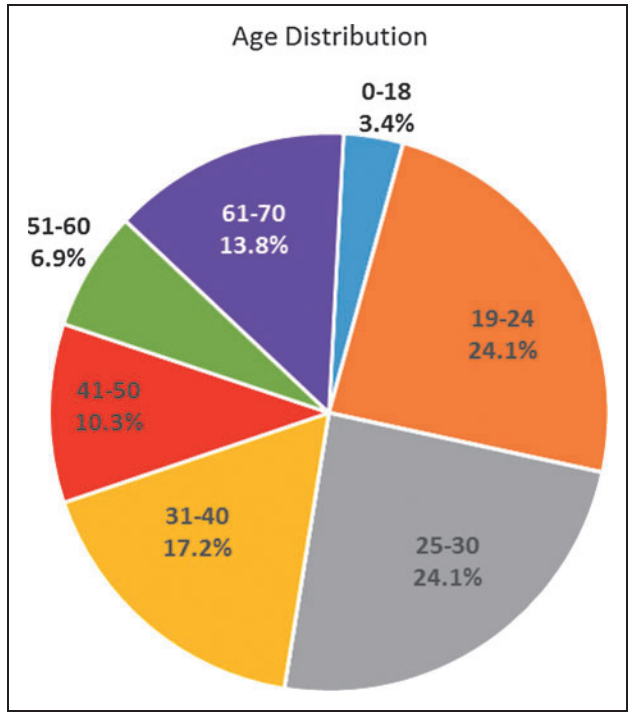

Fig. 3. Age distribution of Zooniverse participants.

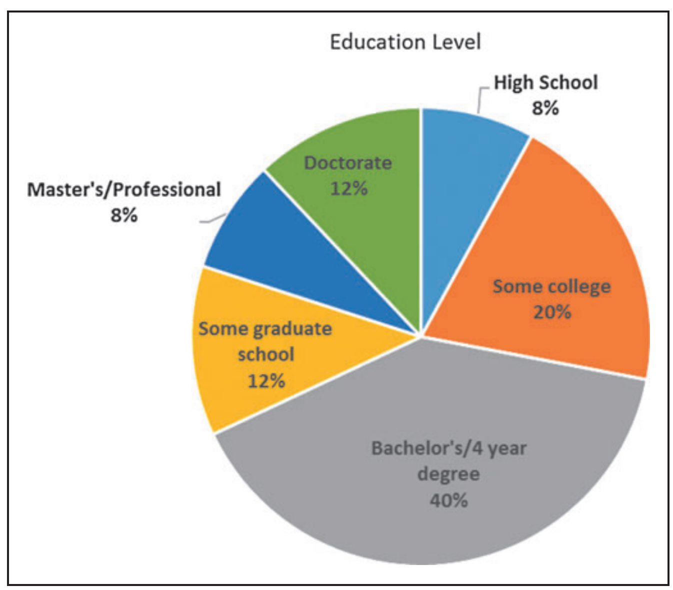

Fig. 4. Education level of Zooniverse participants.

Table 1. Average Sentiment Value for Questions Pertaining to Participation and Interest in Mobile Apps

Evaluate the Following Statements	Average
Rate your interest in space science prior to your participation in Zooniverse.	4.50
Rate your interest in space science after your participation in Zooniverse.	4.73
I have encouraged others to participate in Zooniverse projects.	3.54
I would download and use a mobile app for Zooniverse projects.	3.68
I feel motivated to participate frequently.	4.31
I would participate more frequently if a mobile app were available.	3.21

agreement or positive feelings toward each statement evaluated. With an average of 4.73 out of a possible 5, post-Zooniverse levels of interest in space science rated very highly, even higher than pre-Zooniverse levels of interest in space science (4.50).

These results indicate generally positive feelings toward the potential extension of these projects to app format, with an average of 3.68 when asked whether or not they would download and use a mobile app. The lowest figure was 3.21, slightly above neutral, for evaluating the statement, "I would participate more frequently if a mobile app were available." This value is intuitively the lowest considering the already high participation rates in this sample, supplemented by the general agreement that participants feel motivated to participate frequently (4.31 average). *Figure 5* illustrates a tendency for younger Zooniverse participants to be more amenable than older participants to the idea of downloading and using a mobile app for their citizen science projects. Considering demographic data indicates high participation rates among the middle-aged population, which is less likely to prefer apps; the lower value regarding mobile apps affecting frequency of participation can perhaps also be partially explained by this detail.

These numbers also suggest that participants encourage others to become citizen scientists as well (3.54 average). The most popular smartphone among the survey sample uses the Android operating system (38%), although Apple, Firefox OS, and Windows Phone users were represented as well as nonsmartphone users. On average, the survey respondents have participated in 4.12 different Zooniverse projects with a median of 3 projects per person (*Fig. 6*).

A Pearson's chi-squared test was used to evaluate the relationship between the categories "I would download and use a mobile app for Zooniverse projects" and "I would participate more frequently if a mobile app were available." This test found that a correlation exists between these two categories, with $r=0.867$ and a 95% confidence interval covering values between 0.703 and 0.944. With a P-value of 1.723×10^{-7}, it is safe to consider a positive relationship between these categorical variables.

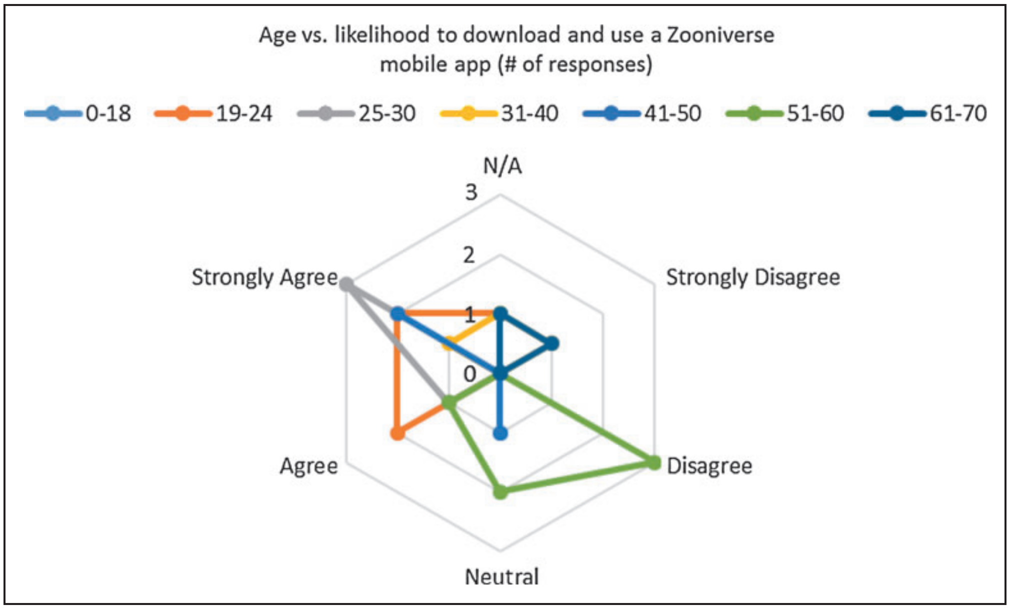

Fig. 5. Age groups mapped against propensity to download and use a mobile app format of Zooniverse projects.

This research is still in a very early stage of identifying what benefits citizen science projects could reap in terms of participation levels if their projects were adapted to mobile app format. If a citizen science project were designed to exist in both web browser and mobile app formats, a detailed study into usage statistics and demographics across both platforms would be welcome in this particular area of study. Based on the limited age information acquired in this study, it may be worth hypothesizing that availability of a mobile app would attract a younger demographic to citizen science.

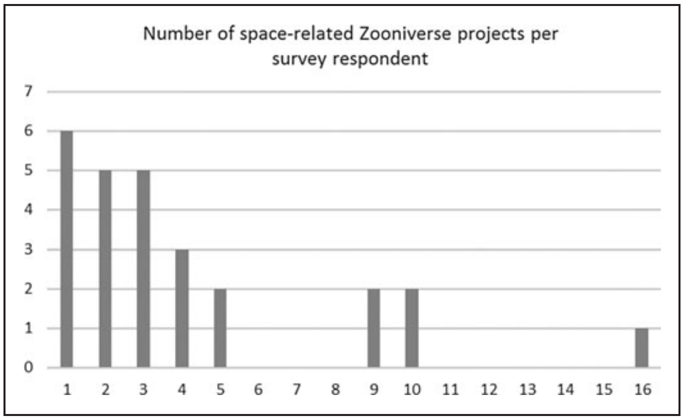

Fig. 6. Number of space-related Zooniverse projects per survey respondent.

POLICY RECOMMENDATIONS AND CONCLUSIONS

NASA should embrace citizen science as a fundamental part of both its outreach and scientific goals. Citizen science should be further promoted and incorporated within NASA Education, the Office of Communications, and other agency divisions. The agency has the potential to serve as a leader in citizen science for other federal agencies through continued use and development of COECI and NASA Solve. It should enable the development of further citizen science efforts by simplifying the project creation process where possible in support of those who might wish to develop their own projects. Additionally, NASA should provide information on appropriate outlets for making use of public participation.

Individuals spend more time using smartphone apps each year. Making a significant effort toward the use of mobile apps for gamified projects targets a platform that is currently gaining popularity. Furthermore, increasing research on effective game design will maximize persistent participation and benefits from research apps on every platform. As NASA has noted with its widespread presence and popularity on Twitter, staying up to date on technology trends allows outreach to the widest audience.

The National Research Council (NRC) conducts the Decadal Surveys for NASA, which the agency uses to determine where the most scientifically valuable or interesting possibilities lie in planetary science, astrophysics, heliophysics, and Earth science. The Decadal Surveys and their ilk have shaped the development of NASA's missions since the 1960s. Due to this central role, periodic reinforcement of the Decadal Survey findings through successful relevant citizen science projects could further demonstrate the importance and public interest in prospective mission areas. If used in such a way, NASA might include citizen science activity in its task statements to the NRC.

NASA should continue to take advantage of its strong social media following. Advertising citizen science projects alongside major mission milestones can encourage enthusiasm for both the project and mission, making participants feel a direct connection to the data coming out of their space agency's activities. The agency should also maintain its strong Twitter presence and encourage relevant missions and departments with citizen science components to participate in social media discussions such as #CitSciChat on Twitter, hosted monthly by SciStarter and the North Carolina Museum of Natural Sciences.

NASA Solve is a useful tool for maintaining an open line of communications with the public on current citizen science opportunities. All varieties of projects, including gamified apps, challenges, *etc*., from NASA and its partners should be included on the website and broadcast to the public via Twitter, Facebook, and Instagram. By broadening NASA Solve's scope to include the agency's partners' projects, awareness for scientific research could be increased and the public further engaged in a wide array of technology- and knowledge-furthering opportunities. The inclusion of information on conferences with citizen science themes could help build the contributor community as well, by showcasing opportunities for active citizen scientists to congregate. An up-to-date site used in conjuncture with the agency's social media outreach would provide awareness to an even larger science-interested audience, which would likely be receptive to contributing to NASA's scientific goals.

The Wilson Center Commons Lab conducted an exploratory study on accelerators and barriers to implementing crowdsourcing and citizen science in federal agencies. Some of the aspects determined to be accelerators were influential "champions" of citizen science within agencies; the legal authority of an individual agency; the existence of and access to personnel to assist in navigating bureaucratic processes; success-story case studies; partnerships with universities, other agencies, contractors, museums, philanthropists, and schools (which can streamline implementation due to less federal bureaucracy); availability of relevant working groups; and a history of executive orders supporting open data.

Barriers to implementing citizen science included the Paperwork Reduction Act (PRA), which led to limited involvement in projects and staff hesitation to develop further projects in one agency, privacy concerns over what can and cannot be collected from members of the public, data quality concerns, liability concerns for the agency and the volunteers, agency demographics tending toward skepticism over the utility of crowdsourced data and analysis, and a lack of funding, success stories, an active "champion," and/or an information technology department capable of setting up a project.

To address these barriers, the report recommended the formation of a clear roadmap of required actions to navigate the bureaucracy of the PRA and privacy policy, designating personnel to field questions along the various stages of the process, encouraged executive directives (such as COMPETES) approving data collection in this manner, adding flexibility clauses to the PRA, and interagency communication.[61]

NASA has shown the ability to overcome some of these barriers and show that others are less severe than other federal bodies might anticipate. Research managers at the agency need to stay current on technology trends in order to reach the widest audience and take note of research into game design to maximize efficacy of citizen science projects while making information on the process and benefits easily accessible through venues such as COECI. The agency is overall on the right track; research indicates that the greatest motivation of citizen science participants is the desire to contribute and they are happy to do so frequently.

Astronomy has a long tradition of amateur involvement, and citizen science is the 21st-century embodiment of this tradition. Citizen science and crowdsourced research, if more thoroughly integrated into program design at NASA, can accelerate the achievement of scientific goals all while increasing citizen engagement in their space agency's activities and even reaching out to a younger audience, women, and other groups not commonly found in astronomy. With continued support from the White House, NASA is and can continue to be a leader in open government and citizen science, using its greatest resource to meet great challenges.

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