Astro 2020 State of the Profession White Paper: EPO Vision, Needs, and Opportunities through Citizen Science

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Abstract

Citizen science has become an invaluable asset for conducting astronomical research, enabling the public to work alongside scientists in data collection, classification, and analysis, and adding to an ever-growing record of novel discoveries. It has the ability to engage hundreds of thousands of volunteers in the scientific process, effectively blurring the boundary between the public and professional science practitioners. While many of our astronomical institutions are philosophically onboard with the cultural shift, much work remains. To maximize the potential of citizen science to advance astronomical research, science literacy, science self-efficacy, positive attitudes towards science, and inclusiveness over the next decade, we recommend the following actions be taken: 1) investment in shared citizen science resources; 2) institutional incentives and facilitation of astronomy professionals working with education, outreach, and communication professionals on citizen science efforts; 3) incorporating citizen science plans as early as the conceptual design phase of new astronomy missions and ground-based projects; 4) publication of evaluation efforts documenting best practices and impacts; 5) increased support for development and maintenance of infrastructure for citizen science; 6) continued incorporation of explicit language in funding solicitations that encourages the use of citizen science; and 7) funding for centralized science communication and media training. We highlight here the achievements of citizen science as a tool for both research and public engagement. Additionally, we provide a vision for utilizing citizen science as an accelerator for astronomical discovery, learning, and positive cultural change.

1 Vision & Call to Action

Since the 2010 'New Worlds, New Horizons in Astronomy and Astrophysics' decadal survey, we have made enormous progress in establishing public participation in scientific research (known as citizen science) as a unique and effective tool in helping science and society cope with the ever-growing data rates and volumes that characterize the modern research landscape. Across the disciplines, citizen science efforts are enabling research that otherwise would not be possible, from discovering an exotic 4-star planetary system [57] to designing new molecules for fighting Tuberculosis [36] to documenting the impact of climate change on plant and animal species [48]. Over the past decade, hundreds of publications have documented and established the robustness and reliability of crowdsourced data. For example, data from Zooniverse, the world's largest platform for citizen science (described in detail below), has been used in over 150 peer-reviewed publications across many disciplines, including astronomy ([25], [24], [43], [26], biomedicine ([18]), climate science ([22], [23]), ecology ([21], [20]), and the humanities ([29], [19]). These efforts have established the quality and reliability of data produced through citizen science efforts.

The America COMPETES Reauthorization Act of 2010, the Crowdsourcing and Citizen Science Act of 2016, and the 2019 White House report by the Office of Science and Technology Policy [50] all highlight the critical role citizen science plays in facilitating research projects that investigate questions from data at scales beyond the resource capacity of the professional research community. For example, in FY17 and FY18, between 5,000-10,000 participants contributed over 18,000 hours of effort to Aurorasaurus, a citizen science project developed around observing aurora, described in detail below. On Zooniverse, over 100,000 classifications are submitted each day. An average dataset on Zooniverse would take $\sim$37 years for a professional researcher alone to classify, whereas an average Zooniverse project is completed within 2 years [11]. These citizen science efforts are enabling research that would otherwise not be practical or possible.

As well as impacting large-scale research, studies have shown that citizen science can have a positive effect on the citizen scientists themselves. Outcomes include increases in long-term environmental, civic, and research interests (e.g., [17] and references therein), the increased representation of women and minorities in the scientific process [31], as well as increases in science self-efficacy [55, 54, 47, 30], scientific literacy [12, 13, 34, 59, 49, 42, 41, 2, 6, 4, 32, 15], domain knowledge [6, 47], and the understanding that scientific progress is a collective process [56]. In §2 we highlight a few case studies to provide more detail regarding the attitudinal and learning impacts for both K-12 and life-long learners as a result of participation specifically in astronomy-based citizen science efforts.

In the companion Astro 2020 Trouille et al. White Paper on 'Needs and Opportunities for Citizen Science as a Core Component of our Research Infrastructure' we provide recommendations for ensuring the long-term sustainability and impact of shared citizen science cyberinfrastructure for research and discovery. Here we are focused on the EPO vision, needs, and opportunities through citizen science. **The following recommendations clarify what needs to be done by the professional astronomy community and our funding agencies to realize the full EPO and scientific potential of citizen science efforts in the coming decade.**

1.1 What do we need from the professional astronomy community to realize this vision?

The professional astronomy community has greatly benefited from the early adoption of and continued leadership in citizen science. Central to our community's citizen science best practices (see §2) is the recognition that without the research community's support, engagement, and buy-in, none of the impacts are possible. Professional astronomers are essential and core partners in seeding citizen science with real research questions, providing research and data science expertise, spearheading engagement with the public, and disseminating results through publications, conferences, accessible databases, etc.

In this next decade, in order to fully take advantage of engaging the public in real research, it will be essential to align our professional astronomy community initiatives and resources with the following recommendations.

Recommendation 1) *Investment in and adoption of shared citizen science resources, tools, and platforms.*

In §2 we describe the best practices that have emerged over the past decades (and centuries) of citizen science. Citizen science efforts that produce quality data for research AND effectively engage the public require a broad range of expertise: project managers, astronomers (including research and data science expertise), education and/or outreach specialists, and communication specialists (including social media engagement). If the citizen science project relies on a web-based platform, web developers, mobile developers, infrastructure engineers, and UI/UX designers are also required. In order to understand impact, citizen science programs should also partner with evaluators and education/social science researchers.

Citizen science platforms like Zooniverse and others described in §2 have established the reliability of the crowdsourced data produced over time, and have subsequently built trust with both the public and the professional research community. Creating robust and reliable citizen science platforms and programs requires a tremendous amount of resources due to the range of expertise and amount of time required to build reputation and trust. With each new citizen science initiative, the key initial step is to review the existing citizen science tools and resources and explore collaborations and partnerships that build on established, communal tools and resources.

For example, when astronomers Jackie Faherty, Marc Kuchner, Aaron Meisner, Adam Schneider, and collaborators recognized an opportunity through citizen science to search for brown dwarfs and other objects at the edge of our Solar System using NASA's Wide-field Infrared Survey Explorer (WISE) data, they did not build their efforts from scratch, at tremendous time and cost. Instead they used the Zooniverse Project Builder[1] to create their online citizen science project BackyardWorlds.org. The Zooniverse's free, browser-based DIY platform meant that the actual build of their project took them a few hours, rather than hiring a team of web developers and designers for 9-18 months (the average build time for a custom Zooniverse project prior to the launch of the DIY platform). Backyard Worlds: Planet 9 launched in February 2017 and to date has received over 5 million classifications from more than 150,000 participants. They have discovered over 100 new brown dwarfs so far, with an additional 1000 candidates awaiting confirmation (see [38, 16]; in these two publications, seven citizen scientists are co-authors alongside the researchers).

[1] zooniverse.org/lab

Recommendation 2) *Institutional incentives and facilitation of education, outreach, and science communication professionals/departments to work alongside astronomy professionals/departments in citizen science efforts.*

Citizen science removes the barrier between scientists and the public, but our institutions have been built and organized around this barrier for decades, with education and research functioning separately. Through citizen science efforts, we have an opportunity to bring together professional astronomers and their institution's communication, design, and education professionals. Their respective expertise will strengthen the research impact as well as the accessibility, relevance, usability, reach, and impact of the citizen science activities.

In 'Recommendation 1' we advocate for the investment in and and use of shared citizen science resources, tools, and platforms. Here we are recommending that when a research team engages in citizen science (ideally using a shared resource/tool), they directly engage their institution's education, outreach, and science communication professionals to fully materialize the EPO impacts of their citizen science efforts. Historically, EPO within astronomy has been led by individual astronomers who are passionate about EPO (yet are rarely compensated or rewarded for their time in EPO and science communication). While these individual efforts are beneficial, astronomers are not expected to have expertise in marketing, social media, recruitment, or integrating citizen science activities into the formal education curriculum. A team of EPO experts can advise and assist with these areas, which are essential to build successful activities that are accessible at scale (see Bauer et al. Astro2020 Decadal Survey EPO white paper for further recommendations).

In order for astronomers to overcome the institutional and cultural barriers that divide them from their EPO colleagues, it will be necessary for astronomy department chairs, University deans, NASA centers' leadership, etc. to provide incentives, encouragement, and guidance.

Recommendation 3) *New astronomy missions and ground-based projects should incorporate citizen science into development, as early as the conceptual design phase.*

First, the astronomy community has a responsibility to champion citizen science as an exciting option in our EPO portfolio. From conception of all new missions, major telescope builds, etc., citizen science opportunities (e.g., in data collection, data processing, analysis, etc.) should be explored and weighed for appropriateness and impact as part of the mission's strategic planning effort. Second, citizen science pathways should be designed as the science mission is being designed and, when appropriate, should launch in tandem with the mission launch. In §2 we describe the positive learning and attitudinal shifts that result from the public being engaged through citizen science. The chance for discovery can be a major motivator for participation in citizen science [54]. It is a missed opportunity, both in terms of research impact and public engagement, if citizen scientists do not have the ability to contribute to the data processing/analysis as early as possible.

In one example, the LSST EPO team partnered with the Zooniverse team to design and implement the integration of citizen science efforts into the LSST research and EPO efforts. This early decision and funding has enabled the Zooniverse web development team to work with the LSST Data Management and EPO teams to build the infrastructure that will allow astronomers to seamlessly create citizen science projects with LSST data. While the Zooniverse-based citizen science pathways are being built directly into the LSST pipeline, the specific projects will be spun up by the community based on emergent trends in the data and research. The ability to quickly develop new Zooniverse projects as the data dictates is essential in providing the flexibility required to enable new discoveries and adapt as the community learns what will be most useful.

Recommendation 4) *Allocating resources and publishing the results of evaluation efforts documenting over-arching best practices and impacts of citizen science efforts.*

Over the past decade, the field of citizen science has matured and professionalized. The many publications documenting the robustness and reliability of crowdsourced data have convinced the community that citizen science is a valid and essential tool when conducting research in astronomy (see e.g. [60]). However, too little has been published around citizen science best practices and EPO impacts. For example, the field lacks baseline information on demographics of participants engaging across astronomy-related citizen science efforts. There are also numerous open questions; e.g., What are the benefits and constraints when designing a citizen science system that optimizes learning opportunities over science output? What are the best practices for engaging museum guests in citizen science? How much stronger are the learning and attitudinal gains when a professional astronomer is directly engaged in communicating the science with their volunteers versus that effort being carried out only by communication specialists?, etc.

In the coming decade, we must allocate the necessary resources and publish on citizen science best practices and EPO impacts. Citizen science projects and platforms should partner with researchers with expertise in the social sciences, learning sciences, and education research and evaluation studies should be informed by best practices in those fields.

As an example, the Zooniverse has fostered collaborations with education and social science researchers over the past decade and the platform has greatly benefited from the insights and best practices that have emerged from these 'meta' studies. Of the over 150 peer-reviewed publications listed at Zooniverse.org/publications, 38 are 'meta' studies that include but are not limited to: the effects of gamification (e.g., [30, 27]), online community dynamics ([44]), exploring models for human-machine integration (e.g., [14]), and the positive impacts of citizen science on participants' attitudes and learning (described in more detail in §2).

1.2 What do we need from funding agencies to realize this vision?

Over the past decade, citizen science has seen increased funding support from National agencies such as the NSF, NASA, NOAO and others. For example, Figure 1 shows the growth in awards made by NSF mentioning citizen science from one in 1998 to over 130 in 2016. Furthermore, the recent White House Office of Science, Technology, and Policy report documents increasing recognition of the importance of citizen science as a mechanism for carrying out research as well as engaging the public [50].

However, we note a sharp decrease over the past three years in the number of NSF grants awarded mentioning citizen science (see Figure 1). There are also a number of critical issues faced around the long-term funding sustainability of the shared citizen science platforms our community relies on. Against this backdrop, we list recommendations for funding agencies to ensure that we reap the full benefits of citizen science for astrophysics endeavors through 2030 and beyond.

Recommendation 5) *Increasing support for development and maintenance of cyberinfrastructure for citizen science.*

Much of the agency support rightly goes to funding research or education that incorporates citizen science in some way. However, in a manner similar to large astrophysics projects that require development, deployment and maintenance of data pipelines, the infrastructure for deploying citizen science must also be supported beyond the development phase. We note that in calculating the

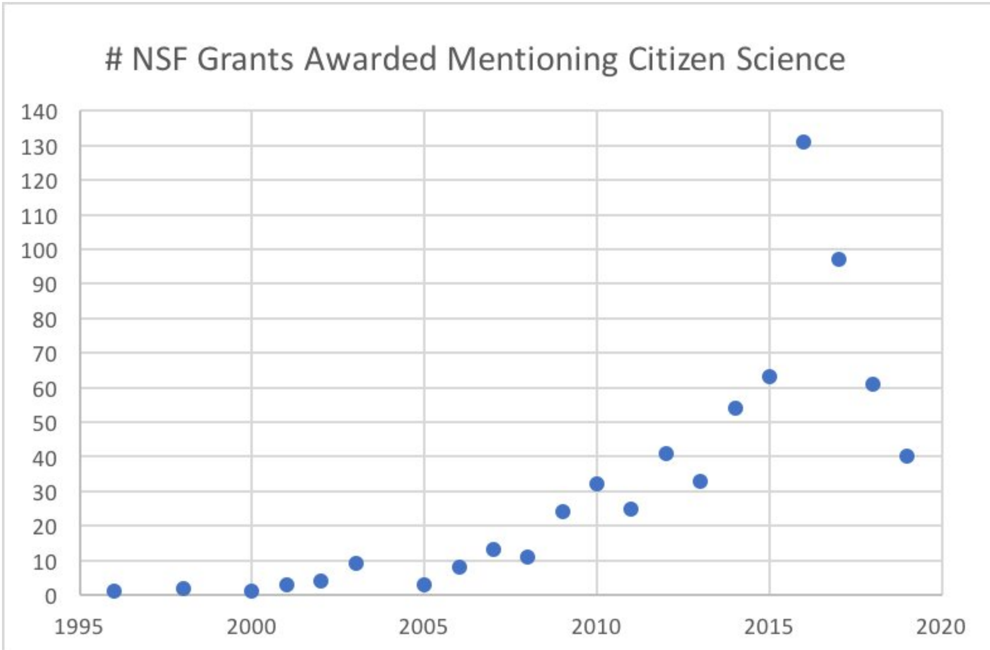

Figure 1: *The number of NSF grants awarded over time based on a search of both current and expired awards with the simple search term "citizen science".*

cost of supporting a citizen science effort, it is important to include not only the cost of creating and maintaining the software and/or web infrastructure the effort relies on, but also salary support for the project managers, researchers, and educators leading the effort. However, there are few, if any, opportunities through agency solicitations to request funding for general maintenance and staying current with the modern web infrastructure landscape. We recommend that a funding pool be identified that encourages submissions for these sorts of expenditures. Naturally proposals to this pool would need to include well-justified arguments for the science that is supported and the need to sustain the current infrastructure, but there should be no requirement that the requested funds generate "new" cyberinfrastructure. In this manner, agencies would not be obligated to sustain citizen science cyberinfrastructure past the point of its utility, therefore leading to natural, planned sunsetting.

Recommendation 6) *Continue to incorporate explicit language in funding solicitations that encourages use of citizen science in research and education proposals.*

The publication of the Crowdsourcing and Citizen Science Act of 2016 is (perhaps not coincidentally) correlated with the peak of funding for NSF projects related to citizen science, as seen in Figure 1. Several NSF communiques, such as Dear Colleague Letters, about engaging the research community in support of citizen science were also first sent in 2015 and 2016[2].

We recommend that explicit language continue to be issued by agencies to seek proposals related to citizen science. For example, in the 2019 NASA ROSES solicitation, explicit wording encouraging the submission of citizen science proposals has been included. We further recommend

[2] e.g. https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=136445 and https://www.nsf.gov/pubs/2016/nsf16059/nsf16059.jsp

that agencies continue to hold workshops and use other mechanisms as needed to obtain *researcher* community input and buy-in on the evolving uses of citizen science as a research method. It is important that the funding agencies do not succumb to seeing citizen science funding as a "fad," but continue to support the process of integrating it into the basic toolkit of research professionals. To this end, we also recommend that in order to incentivize the formation of National-scale collaborations for citizen science, solicitations such as those for Science & Technology Centers or Research Collaboration Networks explicitly incorporate language supporting citizen science.

Recommendation 7) *Funding agencies allocating resources for shared science communication/media training for researchers across the country.*

In addition to our recommendation that professional astronomers partner with communication specialists at their institutions (as described in §1.1 'Recommendation 2'), there is a tremendous opportunity through citizen science to provide science communication training directly to professional astronomers. This is currently done mostly through ad-hoc, informal experiences. Instead, we recommend that funding agencies support the development of centralized, coordinated, robust science communication training resources, crafted collaboratively by experts in science communication and professional astronomers leading citizen science efforts. As shown below, core to the success of citizen science is that the professional astronomer is directly engaging with their citizen scientists. U.S. funding agencies could look to approaches used in Australia to provide centrally organized science communication and media training opportunities that have greatly benefited that community[3].

2 Case Studies and Impacts of Citizen Science

Over the past decade, best practices have emerged to optimize the impacts of citizen science. These include 1) the opportunity for the public to contribute to real research; 2) a menu of options for the public to engage, with a low barrier to entry; 3) citizen scientists having access to the data alongside professionals; 4) direct communication between researchers and the citizen scientists; and 5) clear and ethical privacy policies.

The Citizen Science Association's[4] 'Citizen Science: Theory and Practice' journal[5] provides a growing literature around best practices in citizen science. The European Citizen Science Association[6] have also compiled guidelines for citizen science efforts[7]. The recent 2019 NASA Science Mission Directorate Policy Document for Citizen Science[8] was informed by these guidelines and the broader citizen science communities' efforts over the past decade.

Below we highlight a few example case studies showcasing impacts in formal and informal learning environments on K-12 and life-long learners. We note that this is not meant to be an exhaustive list; only suggestive of the range and types of platforms/experiences. See CitizenScience.gov and SciStarter.org for general listings of citizen science projects across the disciplines.

[3]E.g., https://scienceandtechnologyaustralia.org.au/what-we-do/super-stem-communicator-workshop/
[4]https://www.citizenscience.org/
[5]https://theoryandpractice.citizenscienceassociation.org
[6]https://ecsa.citizen-science.net
[7]https://ecsa.citizen-science.net/engage-us/10-principles-citizen-science
[8]https://smd-prod.s3.amazonaws.com/science-pink/s3fs-public/atoms/files/SPD%2033%20Citizen%20Science.pdf

2.1 Informal Learning: Example Case Studies

Online Data Processing/Analysis: The world's largest platform for online citizen science is Zooniverse[9]. It began in 2007 with a single project called Galaxy Zoo. The goal of the project was to process just under one million images of galaxies from the Sloan Digital Sky Survey into single morphological categories. Several hundred thousand volunteers participated, and not only did they complete the task in a matter of months, but each image was classified an average of 38 times. The results of the initial Galaxy Zoo project suggested that the general public could reliably classify large sets of galaxies with a similar accuracy to professional astronomers [43]. The success of Galaxy Zoo led to the foundation of the Zooniverse platform, which currently hosts more than 90 active projects in partnership with hundreds of researchers across the disciplines and a volunteer community of 1.7 million registered participants in 234 countries. Among online citizen science platforms Zooniverse is unique, due to its 1) shared open-source software, 2) reliable, flexible, and scalable Application Programming Interface (API), 3) the Project Builder, a DIY tool which allows anyone to build their own project for free, and 4) the size and scale of its audience.

Of the over 150 peer-reviewed publications listed at Zooniverse.org/publications, 38 are 'meta' studies.The articles documenting positive impacts on participants' attitudes and learning include [47] and [52], who found increases in domain knowledge and conceptual understanding through participation in Zooniverse astronomy projects, and [44] who found significant vocabulary shifts to more sophisticated scientific language between Zooniverse citizen scientists first and last 10% of posts on the project discussion forums.

Cosmoquest[10] is an online citizen science platform engaging the public in mapping the surfaces of our Moon, Bennu, Mercury, Mars, and the Earth. Alongside these citizen science efforts is the Cosmoquest Educator's Zone[11] providing classroom materials and curricula, as well as robust social media, podcasts, and live streams. By coupling the citizen science platform closely with social media and science communication channels, Cosmoquest promotes enthusiasm and interest, reaches broader audiences, and reinforces and magnifies their EPO impacts[12].

Data Collection/Analysis: It is important to note that the citizen science of today builds on centuries of amateurs contributing to scientific progress. Until the 19th century when science became more professionalized, most science was carried out by well-educated generalists[13]. The American Association of Variable Star Observers (AAVSO) formed in 1911, building on the work of previous U.S. amateurs. [53] studied the AAVSO's Citizen Sky project and documented the best practices in design principles that emerged, as well as the attitudinal shifts amongst citizen scientists that resulted. The design principles that contributed to positive impacts were 1) the citizen scientists' contributions were necessary and meaningful, 2) the platform provided web-based resources through which citizen scientists could interact with peers and the scientists, 3) the scientists played an active role in teaching and communication, 4) the platform supported citizen scientists' analysis and presentation of their own data and results, and 5) citizen scientists were encouraged to become active members of the research community. In terms of attitudinal

[9]https://www.zooniverse.org/; see zooniverse.org/publications

[10]https://cosmoquest.org

[11]https://cosmoquest.org/x/educatorszone/

[12]See https://cosmoquest.org/x/the-science/publications for publications

[13]https://www.aavso.org/sites/default/files/jaavso/PercyEditorial471%282019%29.pdf

shifts, the most positive shifts were in overall attitudes towards science. Participation in the social components of the program was significantly related to improvements in scientific literacy (while other project participation variables, like the amount of data contributed, were not) [53].

Aurorasaurus[14], started by the New Mexico Consortium with NSF funding in 2012, engages the public in observing the aurora. Aurora sightings and images are captured through a platform featuring smart phone apps, digital camera observations, alerts, and validated mining of geo-coded text-based social media sources like Twitter [9]. There are no other real-time verified sources of data indicating accurately where the dynamic aurora are visible (e.g., no imaging satellites, and no cameras that extract the actual locations). In addition, for larger, more equatorial, and less common auroral events, fewer traditional data sources (e.g., ground-based scientific cameras) exist to document these rarer phenomena (e.g., the discovery of the newly recognized STEVE aurora-like phenomena [45]), thereby increasing the need for citizen scientists to contribute. This is a unique opportunity for the public who are interested in this information and the scientists who use these data to supplement traditional sources of data about the aurora. NASA estimates 5,000 to 10,000 participants contributed over 18,000 hours in FY17 and FY18. Their effort, alongside the research team, has led to publications in Heliophysics verifying and improving space weather models, in machine learning and human-computer interactions fields, and in citizen science journals demonstrating how people can robustly detect and document previously unknown auroral features [10]. Through Aurorasuarus, contributions from citizen scientists have energized the public and personnel throughout NASA in a multitude of ways, including being featured in a documentary and a variety of media outlets; e.g., Science Friday, Space.com, the *New York Times*, Discovery News.

Globe at Night (GaN) is a flagship program of the National Optical Astronomy Observatory (NOAO). During ten days per month of moonless evenings, citizen scientists worldwide record the night sky brightness as part of a ‘star hunt’ for the faintest star visible. Once this is complete, they submit their data using the GaN app[15]. In thirteen years of the program, 188,000 observations from 180 countries have contributed to a light pollution map. These data have been used by dark sky advocates to strengthen lighting laws where they live [1], by college students to study seasonal trends in nightly sky brightness averages within a city compared to mountaintop observatories [40, 39], by a winning 5th grader in a regional science fair investigating the habitats of night birds, and by middle school and upper elementary students to visualize their 3700 GaN data points as a 35,000 piece Lego map. In 2009 and 2015, GaN was an official citizen science campaign for the United Nation-sanctioned International Years of Astronomy and of Light. To maintain the community and create new partnerships, GaN has partnered with the Girl Scouts and SciStarter in “Think Like a Citizen Scientist”, and with STARS4ALL’s Light Pollution Initiatives, and most recently in the IAU100 Global Project “Dark Skies for All”.

Other examples of this type include Radio JOVE[16], Citizen CATE[17], SETI CAMS[18], and the Pro-Am Collaborative Astronomy (PACA) Project. Through PACA several hundred global amateur astronomer observers and robotic telescope networks observe comets, planets, and solar eclipses. In 2017, The PACA Project and Citizen CATE partnered as PACA_PolNet to acquire polarimetric information about the solar corona during the Total Solar Eclipse (TSE). The upcom-

[14] www.aurorasaurus.org; data can be accessed at https://zenodo.org/record/1255196#.W79tlxNKjs0, [37]

[15] www.globeatnight.org/webapp/

[16] https://radiojove.gsfc.nasa.gov

[17] https://eclipse2017.nso.edu/citizen-cate

[18] http://cams.seti.org

ing 2024 TSE across North America and the 2019 and 2020 TSEs from Chile to Argentina provide exciting opportunities to build on the 2017 TSE successes.

After-School and Out-of-School-Time Programs: The Adler Planetarium's Teen Programs efforts use citizen science to serve Chicago's most under-resourced communities. For example, Adler's Aquarius Project is the first ever teen-driven underwater meteorite hunt. A partnership between the Adler, the Field Museum, the Shedd Aquarium, NASA, and NOAA, the Aquarius Project put teens in the driver's seat to search for the bright green fireball that streaked across the sky in 2017. Over 1000 teens have participated, from mapping a previously unexplored area of Lake Michigan to iteratively designing and building a magnetic retrieval sled, and even going on boat expeditions. They have communicated their successes and failures through the National Geographic Open Explorer Platform[19] and publications [35, 5]. Programs like the Aquarius Project provide authentic research experiences through long-term, deep engagement, building community between Chicago teens, Adler, and the broader research community, and creating pathways for Chicago youth into STEM workforce opportunities as a result.

2.2 Formal Classroom Settings: Example Case Studies

As the field of citizen science matures, there are a growing number of quality opportunities for instructors to engage their students in authentic research through citizen science. Citizen science in classroom settings provides unique, hands-on opportunities to engage students in the process of scientific discovery while making real and valued scientific contributions and is well aligned with research-supported educational practices [51, 28, 33]. See Trouille et al.'s chapter on 'Citizen Science in Astronomy Education' in the forthcoming IoP book titled, "Astronomy Education: Online Formal and Informal Learning" for more details and example case studies.

Online Citizen Science: Variable Star Astronomy[20] (VSA) is the web-version of the American Association of Variable Star Observers (AAVSO) hands-on Astrophysics educational project. By carrying out all aspects of the research process, students develop and integrate skills in science, math, and computing through variable star observation and analysis, motivated by the excitement of doing real science with real data. The materials are appropriate for middle school through introductory college level classes. As described in the instructor's guide, except for a few exercises in skill development, there are no "right" answers, only the data obtained and the results of the analysis of that data by students. Students contribute to variable star research by sharing their investigations and observations through the AAVSO database.

In Astro 101 courses for undergraduate non-STEM majors, a notable example of integrating citizen science is Slater et al.'s use of a backwards faded scaffolding approach in which students carry out multiple citizen science based mini-inquiries throughout the semester [58]. Building on this success, Zooniverse's classroom.zooniverse.org effort provides a Galaxy Zoo-based small group research experience. In some citizen science projects and approaches, instructors must spend considerable time and effort training students so that they are able to make meaningful contributions. In contrast, this resource enables students to provide useful and valued classifications to a Zooniverse project within minutes of entering the site. By working within an online citizen science

[19] https://openexplorer.nationalgeographic.com/expedition/rovmeteoritehunt
[20] https://www.aavso.org/education/vsa

platform, we provide a complementary approach to fieldwork-based citizen science experiences, removing geographic barriers as well as resource constraints for institutions with limited access to active researchers and/or who are unable to sustainably carry out fieldwork.

Preliminary results from the classroom.zooniverse.org efforts indicate positive impacts on students' attitudes towards science and understanding of the processes that astronomers carry out in pursuing their research. Students also showed a slight increase in self-efficacy, as they were less likely to agree that 'only a few specially qualified people are capable of understanding science' and more likely to agree that 'nearly everyone can understand science (if they work at it)'. They were also more likely to agree that they themselves were 'capable of learning science' and 'making contributions to scientific knowledge'.

Citizen Science Data Collection Projects: Several formal classroom astronomy citizen science efforts have engaged students, teachers, and members of the public in data collection to help address scientific investigations. One such example is the Research and Education Collaborative Occultation Network (RECON) project which involves over 55 communities stretching across the Western United States from Canada to Mexico [7]. The research goal, to measure the sizes, shapes, moons, rings, and other characteristics of trans-Neptunian Objects (TNOs) using stellar occultation measurements, required a network of telescopes spanning 2,000 km with approximately 50 km spacing. Telescopes and camera equipment were shipped to participants, and training was provided via three, four-day long intensive workshops. RECON teams participate in six to eight occultation campaigns per year. Data is recorded electronically and transmitted to the central data repository where it is then analyzed by project leadership working with undergraduates. Over the course of the project, an average of 85 adults, 46 K-12 students, and nine college students participate in each full network occultation campaign. The project has successfully measured a Centaur [8], a classical Kuiper Belt Object [3], and an extreme TNO [46] along with additional measurements of Pluto and other TNOs (in preparation).

3 Summary

Citizen science has become a major contributor to quality astronomical research by involving the public in the research process through data collection, evaluation, and analysis. Through citizen science, researchers can process massive datasets accurately and efficiently with the help of enthusiastic volunteers. In this paper, we highlight the achievements of citizen science both in formal and informal learning settings. Additionally, we include a set of 7 recommended actions to align our professional astronomy community initiatives and resources to realize the full potential of citizen science EPO impacts: 1) investment in shared citizen science resources, 2) facilitation of collaboration between EPO and astronomy professionals, 3) incorporation of citizen science into the development of major astronomy missions and ground-based projects, 4) assessment and publication of best practices in citizen science, 5) increased support for citizen science cyberinfrastructure, 6) continued incorporation of explicit language in funding solicitations encouraging the use of citizen science in research and EPO proposals, and 7) allocation of resources for centralized communication/media training for researchers nationwide.

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