

Institution: University of Oxford		
Unit of Assessment: 9: Physics		
Title of case study: Zooniverse: Harnessing Citizen Science for Global Impact		
Period when the underpinning research was undertaken: 2008 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed:
Campbell Allen	Lead System Architect	2014 – now
Kate Land	Glasstone then Christ Church JRF	2006 – 2008
Christopher Lintott	Researcher; Professor of Astrophysics	2006-14; 2014-now
Philip Marshall	Royal Society URF	2010 – 2013
Brooke Simmons	Henry Skynner Fellow; PDRA	2012 – 2015
Robert Simpson	PDRA	2010 – 2015
Rebecca Smethurst	Christ Church JRF	2018 – now
Arfon Smith	PDRA/developer	2011 – 2013
Aprajita Verma	UK Gemini Supp Sci; UK E-ELT Dep Proj Sci	2006; 2009 – now
Darryl Wright	PDRA	2016 – 2017
Period when the claimed impact occurred: 1 August 2013 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? Y		
1. Summary of the impact (indicative maximum 100 words)		
<p>The Zooniverse is a citizen scientist platform underpinned by research from Oxford Physics that has engaged over 2,100,000 registered volunteers in 248 projects over a broad range of topics, including the arts, biology, climate, history, language, literature, medicine, nature, physics, social science, astronomy and astrophysics. The benefits that have arisen from the different projects made possible by the Zooniverse include: improved disaster relief response, where volunteers on the Planetary Response Network project have provided rapid and responsive analysis of satellite imagery; changes to environmental policy, where the boundaries of Marine Protected Areas have been redefined as a result of improved penguin population data from the Penguin Watch project; enhanced teaching in schools via programmes such as ZooTeach, which has engaged school children in the Bash the Bug and Plastic Tide Projects; and benefits to the well-being and engagement of the citizen scientists involved in the Planet Hunters project.</p>		
2. Underpinning research (indicative maximum 500 words)		
<p>Zooniverse has its origins in the Galaxy Zoo project, pioneered by Prof Chris Lintott at Oxford Physics, which aimed to involve citizen scientists (CSs) in the morphological classification of galaxies, which is best done by the human eye. Millions of potentially interesting astronomical objects are sampled by ground and space-based platforms such as the Sloan Digital Sky Survey and the Hubble Space Telescope, and therefore a sustainable solution was needed to analyse this volume of data. In 2008, work led and conducted by Oxford Physics showed that newly developed software allowed access to a large audience, and that their classifications could be combined to produce a consensus. CSs were asked to classify galaxies into 6 different morphological categories. Accurate measurement of morphology encodes the system's history and can be correlated with other physical parameters. [1] showed that CSs could perform classifications with sufficient accuracy (when cross referenced with each other) that the data could be used in scientific research. Further work published in 2011 (substantially carried out in Oxford, in collaboration with the Adler Planetarium, Yale, Nottingham, Brookhaven National Laboratory, Portsmouth, Johns Hopkins, LinkLab and Fingerprint Digital Media) developed new techniques to measure subtle biases inherent in classification, and thus present measures of classification accuracy which have proved generally useful as a methodology for producing results from CS projects [2], used, for example, in [3].</p> <p>New astronomical projects including the Vera Rubin Observatory's LSST survey will continue the trend to larger and larger surveys, producing 30TB of images and 10,000,000 transient alerts each</p>		

night. This growth, in combination with a desire not to waste volunteers' time, has led to the development of more sophisticated algorithms for both task assignment and developing consensus. Published in 2016 [3], work jointly led by Oxford Physics (design and leadership of the study, plus management of Zooniverse project development), the University of Tokyo, and Stanford, used CS classifications as part of the first Space Warps lens search, and demonstrated that better weighting of volunteers' abilities could increase lens detection rates from 65% to 80%. This was the first large project to offer significant increases in efficiency in this way. The combination of human and machine classifications was explored by an Oxford-led collaboration (with Queen's Belfast, Minnesota, Northwestern, the Adler Planetarium, University of Hawaii and UCSD), in the search for supernovae in data from Pan-STARRS1. They showed that a combination of human and machine classifications allowed for near real-time discovery, and outperformed either method used individually [4]. A recent Oxford-led study (designed and guided by Lintott, who also co-led interpretation of the results with Smethurst) examined the use of Bayesian convolutional neural networks (CNN) for active learning in a human/machine hybrid system [5]. Bayesian CNN, trained on data from Galaxy Zoo, predict the probability distribution for a given morphological feature; the network correctly interprets the uncertainty in volunteer labels, and can be used to select those images where an active learning strategy will most improve the network. This combination of machine and human intelligence reduces the time taken to classify surveys from years (with CS classifications alone) to weeks, and is now deployed on the live Galaxy Zoo site. These early projects (Galaxy Zoo and Space Warps are representative examples) have acted as research projects in how to design effective astronomical citizen science and have provided the basis for how such tasks should be designed for other applications.

3. References to the research (articles in peer-reviewed journals; Oxford authors underlined)

- [1] "Galaxy Zoo: morphologies derived from visual inspection of galaxies from the Sloan Digital Sky Survey" C. J. Lintott, K. Schawinski, A. Slosar, K. Land, et al, *MNRAS* 2008, 389, 1179-1189; doi: 10.1111/j.1365-2966.2008.13689.x
- [2] "Galaxy Zoo 1: data release of morphological classifications for nearly 900,000 galaxies" C. J. Lintott, K. Schawinski, et al, *MNRAS*, 2011, 410, 166-178; doi: 10.1111/j.1365-2966.2010.17432.x
- [3] "SPACE WARPS-II. New gravitational lens candidates from the CFHTLS discovered through citizen science" A. More, A. Verma, P. J. Marshall, et al (including C. J. Lintott, R. Simpson, A. M. Smith), *MNRAS* 2016, 455, 1191-1210; doi: 10.1093/mnras/stv1965
- [4] "A transient search using combined human and machine classifications" D. E. Wright, C. J. Lintott, et al (including C. R. Allen, B. Simmons), *MNRAS* 2017, 472, 1315-1323; doi: 10.1093/mnras/stx1812
- [5] "Galaxy Zoo: probabilistic morphology through Bayesian CNNs and active learning" M. Walmsley, L. Smith, C. J. Lintott, et al (including B. Simmons, R. Smethurst, D. E. Wright), *MNRAS* 2020, 491, 1554-1574; doi:10.1093/mnras/stz2816

4. Details of the impact (indicative maximum 750 words)

As a direct result of the research described above in building projects such as Galaxy Zoo and Space Warps [1]-[5], the Zooniverse Project Builder was released in July 2015, which has allowed users to deploy their own projects, without requiring involvement of Zooniverse staff. This has facilitated a huge expansion of the platform. The Zooniverse has supported 248 projects (of which 92 are currently active) over a broad range of topics, including the arts, biology, climate, history, language, literature, medicine, nature, physics, social science and space. More than 2,100,000 volunteers are registered on the site. Here we detail the impact of the suite of Zooniverse projects that have been launched and sustained in the REF period. The site was especially busy in the period of lockdown in 2020; from March-May more than 40,000,000 classifications were received from volunteers (compared with 19,000,000 in March-May 2019), illustrating the appeal of participation in this sort of community science to its volunteers. Many of these projects involve researchers and datasets from other institutions, but the underpinning research and expertise in citizen science as a scientific tool, along with the leadership, development and implementation, is

an Oxford-led endeavour. We use a few individual Oxford-led projects to illustrate the type of impacts achieved.

Fast satellite imagery analysis resulting in improved disaster relief

The Planetary Response Network project (PRN) was first field tested in 2014 and is led by Brooke Simmons (Oxford Physics until 2015, now Lancaster University) in collaboration with the Oxford Physics Zooniverse team, disaster relief agency Rescue Global and the Oxford Machine Learning Research Group. It allows CSs to analyse satellite images of areas affected by natural disasters in the hours following the disaster, aiding rescue workers on the ground; the requirement for rapid results is only achievable using the tools for efficient task assignment and analysis that were developed as a result of the research described in [1]-[5]. Volunteer analysis identifies sites with structural damage to buildings or roads or with flooding, information is then used to update maps used by disaster response teams. The Network has been mobilised several times in response to natural disasters; here we describe its use for Hurricanes Irma and Maria in 2017, when over 5,000 volunteers performed satellite imagery classification effort which would have taken an expert 8 months in just 3 weeks. Irma struck first in early September, causing catastrophic damage in the north eastern Caribbean and the Florida Keys, and killing at least 134 people. The first satellite image set (of Guadeloupe) was classified in just 2 hours, allowing damage maps to be sent to Rescue Global from the first day of the project; Rescue Global also shared the maps publicly with other NGOs in the region, including S.A.R.A.I.D. According to a report from Rescue Global (19th September 2017): “SARAID used building damage heat maps [of Turks and Caicos Islands] generated by the Zooniverse platform to target priority areas for building damage assessments. 22 buildings were evaluated by the SARAID team including: 3 evacuation shelters, 1 hospital, 1 clinic, 3 schools and 1 government office.” The maps directly benefitted rescue efforts in St Thomas: “In addition to supplying an NGO with satellite communications on St Thomas island, the team also evacuated a small number of patients with critical healthcare needs (including a pregnant lady) to San Juan. Both missions were aided by the heat maps.” **[A]** The flexibility of the Zooniverse interface, in combination with an improved understanding of how best to use volunteers’ time efficiently (studies [3-5]) allowed the PRN team to optimise the use of citizen science tools in real time, and to adjust the priority of what was needed as the situation developed. Hurricane Maria struck just two weeks later, and was regarded as the worst natural disaster in recorded history to affect Dominica and Puerto Rico; the official estimated death toll was 2,975 over the entire affected region. Initially volunteer effort was directed to analysis of satellite imagery from Dominica (as Puerto Rico was covered by cloud), and even before the first heat maps were produced, volunteers had reported damage to an airport, which was directly shared with Rescue Global, who included a specific assessment of the airfield in their aerial surveys. **[B]** When cloud coverage precluded early damage assessment, volunteers were tasked with producing estimates of building density from pre-disaster images, to improve out-of-date census information. Working with partner NGO DART International UK, Rescue Global used the maps of road blockages to more rapidly enable the efforts to clear fallen trees and debris in order to restore critical national infrastructure and gain awareness of accessible locations in which to work. Their Operational Manager commented: “The maps are continuing to be a really (really!) helpful component of our intelligence gathering, especially as the teams have been travelling around Dominica. Information regarding observed concentrations of settlements, road blockages, structural damage and building damage proportions especially, were particularly crucial as they mapped their way around the more isolated communities and health centres. The fact that we are flying regularly between a number of islands, means that ALL of the maps are proving very useful, and those that we are now further from are proving useful for other organisations concentrating in those areas.” **[A]**

Changes to Marine Protected Areas as a result of improved wildlife census

Zooniverse hosts a large array of projects that study the effects of human society on the natural world, to inform policy. These include more than 50 ecology camera-trap projects, which aim to study endangered wildlife and improve their protection; 8 projects that ask CSs to digitize historical climate records and specimens to improve our understanding of long-term climate change; and several projects that track changes in flora, and how these are markers for climate change. The Penguin Watch project asks volunteers (more than 1,000,000 have taken part) to count penguins in images and time-lapse footage captured by remote cameras, satellites, aircraft and drones, and

is led by Tom Hart in the Oxford Zoology department. Penguin Watch, built by the team in Physics working with the zoologists, uses the same underlying platform code that was developed as a result of [1]-[5]; this code has allowed a very large amount of data to be analysed, and provided confidence in the results. Overall, the project monitors more penguin nesting sites than all of the Antarctic Treaty Nations put together, and uses these data to inform discussions on the boundaries of Marine Protected Areas. The South Georgia and South Sandwich Islands Marine Protected Area (SGSSI MPA) was established in 2012 to protect and conserve the region's rich and diverse marine life, and is one of the world's largest sustainably managed MPAs. In May 2019, following a review, legislation was passed to expand the no-take zones to cover 23% of the MPA, a measure that is expected to greatly enhance the protection and conservation of the Territory's rich marine biodiversity. [C] This review was informed by published research from the Penguin Watch project, and by an in-person presentation from Tom Hart at the June 2018 Review Workshop and subsequent discussion [D]. A testimonial from the Director of Fisheries and Environment of the Government of South Georgia and the South Sandwich Islands states: "On the basis of the evidence provided, which was derived from analyses of both tracking devices fitted to penguins and from remote camera data, GSGSSI considered his recommendation to extend the 'No Take Zone' (NTZ) around the South Sandwich Islands. This advice included extending the NTZ from 3km out to 50km in order to reduce the potential for competition for food resources between the region's krill fisheries and penguin populations. The rationale behind the extension was to encompass the foraging range of the penguin species in the region as determined by Dr Hart and colleagues' recent research." [E]

Improved understanding, engagement and well-being of citizen scientists

The Zooniverse achieves broad reach, with 2,100,000 registered volunteers. A 2016 study showed that participation in online citizen science increased users' scientific knowledge [G]. A representative recent (June 2019) survey was conducted of users of the Planet Hunters project (a long-standing project, led by Suzanne Aigrain in Oxford, with 13,000 volunteers), where 577 individuals responded to a questionnaire [H]. The data showed that participants came from 56 different countries (with 42% from Europe, 38% from North America and 8% from Australia and New Zealand); 30% had not been enrolled in higher education; 30% had no background in science; 75% were male; a range of ages were included, from under 18s (8%) to over 75s (5%), with 55-64 the most common age bracket (19%). 88% of those surveyed rated their experience of Planet Hunters as 'good' or 'excellent', with 66% engaging because they enjoyed learning about astronomy and 89% because they wanted to contribute to scientific research. 73% reported that they had learnt something through the project. Quotes from the survey reveal impacts on: Pursuit of knowledge beyond the project: "It was the starting point for learning most of what I know today about space telescopes and stellar astronomy.", "I have joined an Astronomy club and even took part in IASC Asteroid Search Campaign"; Well-being: "Zooniverse has been a big factor in making my retirement fun and meaningful", "I owe a lot to planet hunters I have a bad injury to my hand and anxiety so it is a huge help to my recovery"; Community: "friendship with other volunteers", "closer to son and grandson who are also interested", "networking with my friends who also volunteer"; Widening access: "I have a love and long term interest in science but never been able to afford things like uni or degrees and was never able to pursue it... so this sort of thing is great.", "I am mad about science I am self educated and never in a million years did I think I could contribute anything to science", "I dreamed of becoming an astronomer in my youth... it brought me closer to my dream". In a large survey on volunteers across the Zooniverse carried out in April and May 2020, more than two thirds of volunteers said they had sought out new ways to learn about scientific topics, and more than half had taken part in other science-related activities. More than 70% said they would do so in the future.

Inspiring and informing school children and their teachers

Zooniverse offers dedicated resources for educators to share materials that complement the use of Zooniverse projects in schools. Resources are organised by subject area and age level. A recent pilot project to bring project-specific workshops to schools was run in 10 primary schools in South-East England between October 2018 and February 2019, attended by 558 pupils. 8 of the schools were state schools, of which 6 had an Ofsted rating of 'Good', while 4 schools had between 21% and 37% of their pupils receiving the pupil premium. Two hour-long workshops were

created based on the Bash the Bug and Plastic Tide projects, aimed at year 5 and 6 pupils. Questionnaires conducted after the workshops showed [L] that approximately 90% of pupils thought the workshops were enjoyable, and 85% and 67% of students wanted to do more to tackle plastic waste, or find new medicines, respectively. Approximately 80% agreed that they had learnt something new, with the main learning outcomes of the Plastic Tide workshop being that plastic waste is harmful, and that it is widespread; and of the Bash the Bug session being that bugs are becoming resistant to medicines, not all bugs are harmful, and antibiotics can't cure all diseases. They also learnt that scientists are helping to save the planet (20%), don't only work in labs (17%) and everyone can be one (10%). Feedback from the teachers was overwhelmingly positive, both in terms of the effect on pupils: *"It really inspired them in terms of they can do something really valid ... they can do something useful"*, *"[Being a scientist] is a real job you could do. You could fly drones ... my pupils didn't know that before, that scientists do that"*, *"[the workshop] brought it to life. They could actually really see it happen in our world"* and on their own professional practice: *"Interesting to see a completely new way of teaching science. I definitely think it's something I want to use going forward"*, *"There are certain bits of that approach I will take on myself"*. [L]

Inspiring new forms of artistic expression and enhancing museum exhibitions

The Zooniverse has inspired a unique digital art project 'We Need Us' which is a live, online, animated artwork that is generated from Zooniverse metadata. [J] It was commissioned by The Space and the Open Data Institute in 2014, and then recommissioned by the NEEON (North East of North) Digital Art Festival. The Adler Planetarium (partners in the Zooniverse) was the first planetarium in the United States and attracts more than 500,000 visitors a year. It has numerous exhibits that relate to active Zooniverse projects and encourages visitors to the museum to get involved on site via Wi-Fi, and via a dedicated exhibit on the museum floor. [K]

5. Sources to corroborate the impact

[A] Email and report from Rescue Global, October 2017

[B] Talk thread on Zooniverse's Planetary Response Network website, 24 September 2017

[C] South Georgia & the South Sandwich Islands MPA Enhancements Media Release 12/12/18. <http://www.gov.gs/south-georgia-and-the-south-sandwich-islands-mpa-enhancements/>;

[D] a) "Peeking into the bleak midwinter: Investigating nonbreeding strategies of Gentoo Penguins using a camera network" *The Auk*, **2017**, 134, 520-529; doi: 10.1642/AUK-16-69.1. b) Citation in "Peer-reviewed scientific papers informing the MPA Review"; Tom Hart presentation to June 2018 Workshop "Tom Hart - ...and the South Sandwich Islands" with Penguin Watch logo; "Marine Protected Area 5-year Review Workshop 11-12 June 2018" records discussion around presentation. "SGSSI Marine Protected Area 5-year Review Report" brings all parts of the review together. All available at <http://www.gov.gs/docsarchive/environment/#tab-2>;

[E] Letter from Director of Fisheries and Environment, Government of South Georgia and the South Sandwich Islands

[F] "Multi-modal survey of Adélie penguin mega-colonies reveals the Danger Islands as a seabird hotspot" *Scientific Reports* **2018**, 8, 3926; doi: 10.1038/s41598-018-22313-w

[G] "Science learning via participation in online citizen science" K. Masters, E. Y. Oh, J. Cox, B. Simmons, C. Lintott, G. Graham, A. Greenhill, K. Holmes, *Journal of Science Communication* **2016** A07, doi: 10.22323/2.15030207

[H] Results of Planet Hunters survey of volunteers, June 2019

[I] Planet Hunters Zooniverse Evaluation Report 2019, Research Services, University of Oxford

[J] We Need Us digital art project: <http://weneedus.org/>

[K] Corroborator 1: the Vice-President for Science, Adler Planetarium, may be contacted to corroborate activities at the Planetarium

[L] 'Zooniverse to Schools' Evaluation Report, Ben Gammon Consulting, March 2019