Citizen-Driven Data Analysis: A Cross-Sectional Case Study of a Multi-Domain Citizen Science Platform

ABSTRACT
Designing a sustainable citizen science (CS) project requires consideration of a great number of factors. This makes the overall process unpredictable, even when a sound, user-centred design approach is followed by an experienced team of UX designers. Moreover, when such systems are deployed, the complexity of the resulting interactions challenges any attempt to generalisation from retrospective analysis. In this paper, we present a case study of the largest single platform of citizen science projects to date, The Zooniverse. By eliciting, through structured reflection, the experiences of core members of its design team, our grounded analysis yielded four sets of themes, focusing on Task Specificity, Community Development, Task Design and Public Relations and Engagement, supported by two-to-four specific design claims each. Based on these findings, we synthesize a set of design recommendations, drawing comparisons to an extensive body of HCI literature on crowdsourcing and online communities, to gain a better understanding and inform the development of future systems in this space.

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Citizen science, crowdsourcing, interface design

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Online citizen science (CS) has proven to be not only a practical and effective means of solving previously infeasible, large-scale scientific problems, but also a valuable education tool [40], and, for the scientifically curious, an entertaining, and sometimes addictive, past-time [37]. While we can find exemplars of such systems in many shapes and forms, those that have seen the greatest success have excelled at (at least) two things: first, they managed to accomplish the particular set of scientific objectives sought, and, second, they were able to attract and sustain the interest and support of a critical mass of volunteers over time.

Jointly achieving these two goals is, more often than not, a difficult task. The design of a CS project requires consideration of a great number of factors. This makes the overall process unpredictable, even when a sound, user-centered design approach is followed by an experienced team of UX designers. As a result, it poses significant barriers towards establishing CS as a valid and widely accepted scientific methodology, as smaller research groups appreciative of the CS concept cannot be expected to have the expertise and resources that are essential for a purposeful design and user engagement strategy.

This situation is due, in part, to the novelty of the field, but also to the challenges associated with recruiting and catering to a volunteer participant population. Most citizen science projects rely on contributions primarily driven by intrinsic motivations [37, 43]. Their design has to reflect the values of the community of amateur scientists supporting them, and, in the same time, to enable effective problem solving through the crowd. Even if we consider the large body of literature that offers advice and experience reports in building online communities and similar systems [26, 23], many of the issues, including the feasibility of the tasks to be accomplished, the skills they require, or the process used to launch and advertise the project, are unique to the context of citizen science [7, 10]. The aim of this paper is to come up with a set of design guidelines by which this high-dimensional design space can be better understood.

To do so, we studied the largest single platform of CS projects to date, the Zooniverse[1]. By eliciting, through structured reflection, the experiences of core members of its design team, our grounded analysis yielded four sets of themes, focusing on Task-Community Integration, Community, Task Design and Public Relations and Engagement, supported by two-to-four specific design claims each. Based on these findings, we synthesize a set of design recommendations, drawing comparisons to an extensive body of HCI literature on crowdsourcing and online communities, to gain a better understanding and inform the development of future systems in this space.

BACKGROUND AND RELATED WORK
Online CS initiatives can be analysed from a multitude of angles. For the purpose of this work, we consider two of them: a crowdsourcing angle which looks at a CS exercise as an approach to achieve a goal by collecting contributions from a large number of people, and a second one that focuses on the community of citizen scientists that emerges through online activities initiated or facilitated by the CS platform.

Citizen Science
Online citizen science systems have typically enlisted the help of people in three kinds of activities: data collection (e.g., [48]); data analysis (e.g. [45, 14]); and problem-solving (e.g., [19, 8]). [16] also adds that the role of a citizen scientist

[1] The Zooniverse - `www.zooniverse.org`

includes the 'dissemination of these activities on an avocational basis'. The Zooniverse platform [12] fits this description; participants are presented with digital artefacts such as images, video and audio recordings, and other data provided by the particular science teams in charge of each project. In turn, they are asked to identify, classify, and label the data according to instructions provided, again, by the science team.

Research towards designing more effective citizen science platforms has looked at factors affecting task completion and proposed methods to improve the performance of the contributors through, for instance, more refined task selection [7, 18] and scheduling heuristics [19]. Wiggens et al. [46] analysed CS projects as online communities and introduced a model to capture community organization through the relationship between volunteering, digital technologies, and workplaces. Other studies have examined motivations of participants through surveys and structured interviews [36, 38], as well as emergent phenomena such as citizen-led scientific discoveries, specifically how such discoveries stemmed from casual socialisation in the underlying communities [39]. In general, both sets of studies reference some of the vast psychology literature on human motivation to explain continued participation, including altruism, knowledge, community engagement, power, and self-actualisation [11].

Online Communities

Online communities have been studied from many perspectives; from the macroscopic [1] to the individual, such as how members cooperate, compete, and form and re-form groups (e.g., [1]), to how information is shared within and across groups [24], to how characteristics of communities change over time [25]. In addition to the aforementioned studies of citizen science communities, others have looked at, to name a few, question-answering communities such as Yahoo! Answers [13], knowledge sharing on expert sites such as Stack Overflow [44], Wikipedia [20], MOOCs [31], MUDs [3] and MMOs [41]. There are also several studies which have identified how the characteristics of an online community during the early stages of its formation can indicate its future growth and stability [17, 2].

The core of this paper derives inspiration from Kraut, Resnick et al's *Building Successful Online Communities* [23], which addresses the idea of *designing from evidence*, providing a synthesis of relevant theory pertaining to the understanding of communities, alongside methods for translating such theory into design practice. We have structured our main results as *Design Claims* about citizen science platforms to facilitate comparison with their more general counterparts by Kraut, Resnik et al.

THE ZOONIVERSE PLATFORM

The Zooniverse is a Web platform that hosts several citizen science projects. The first Zooniverse project, *Galaxy Zoo*[2], was launched July 2007 and invited volunteers to participate in the morphological classification of images of galaxies [28, 12]. The early success of Galaxy Zoo led the Zooniverse team to branch out to new domains and task types. Table

Project	Launch	Domain	Users	Subjects	Task
Galaxy Zoo*	07-07	S	165,000	890,000	C
Galaxy Zoo* 2	02-09	S	223,965	304,122	C
GZ Mergers*	11-09	S	20,588	58,956	C
Solar Stormwatch	02-10	S	65,971	N/A	C/M
GZ Supernova*	03-10	S	37,150	76,376	C
GZ Hubble*	04-10	S	2,735	200,000	C
Moon Zoo	05-10	S	121,251	435,314	M
Old Weather	10-10	C	32,076	1,090,745	T
Milky Way	12-10	S	66,495	109,459	M
Planet Hunters	12-10	S	167,354	3,063,759	M
Ancient Lives	07-11	H	24,983	153,885	T
Ice Hunters*	08-11	S	15,276	6,300,518	C/M
NEEMO*	10-11	S	485	N/A	C
Whale FM	11-11	N	2,150	15,531	C
SETI Live*	02-12	S	63,609	27,004	C
Galaxy Zoo 4	09-12	S	85,758	365,193	C
Seafloor Explorer	09-12	N	21,112	123,077	M
Cyclone Center	09-12	C	7,210	84,231	C
Bat Detective	10-12	N	2,500	491,221	C
Cell Slider	10-12	B	19,368	275,702	C
Andromeda Project*	12-12	S	10,547	20,106	M
Snapshot Serengeti	12-12	N	31,559	1,545,399	C
Planet Four	01-13	S	43,975	59,442	M
Notes from Nature	04-13	N	6,090	188,551	M/T
Space Warps*	05-13	S	27,514	479,469	M
Worm Watch Lab	06-13	B	6,425	74,016	C
Plankton Portal	09-13	N	5,227	338,060	C/M
Radio Galaxy Zoo	12-13	S	5,044	174,821	C/M
Operation War Diary	01-14	H	10,528	94,656	M/T
Disk Detective	01-14	S	5,252	278,121	C
Condor Watch	04-14	N	3,059	264,066	M
Sunspotter	06-14	S	3,067	210,793	C
Asteroid Zoo	06-14	S	5,332	90,000	M
Floating Forests	08-14	N	1,924	778,506	M
Chicago Wildlife Watch	09-14	N	81	4,052	C
Penguin Watch**	09-14	N	–	178,061	C/M
Higgs Hunters**	10-14	P	–	80,445	C/M

Table 1. Summary of Zooniverse projects past and present, including each project's status as of September 2014. Domains: S – space; C – climate; H – humanities; N – nature; B – biology; P – physics. Tasks: C – classifying; M – marking; T – transcribing. Projects marked with a * have been retired; ** indicates a project that had not launched at time of writing; in more recent projects where participation is possible without logging in this is a lower bound to the total participation rate.

lists all Zooniverse projects order by their launch date, and indicates their status, Web address, subjects being processed, and domain. As of August 2014, Zooniverse has gained over one million active volunteers. *Retired* projects have achieved their classification goals and are now closed. *Active* projects are those still open for new contributions.

METHODOLOGY AND ANALYTICAL FRAMEWORK

In order to examine the underlying decisions, influences, and knowledge responsible for the development of the Zooniverse platform, our study was part of a structured reflection [15] conducted via by core members of the Zooniverse design and management team. This approach allowed the development team to draw upon their own notes, meetings, design decisions, and internal communication records in order to translate their actions into a systematic order, providing the analysis with the required information to bridge the theory-practice

[2]Galaxy Zoo - **www.galaxyzoo.com**

gap [4].

These reflection sessions took place over two days, with two members of the core Zooniverse team, who were with the initiative form the beginning. Audio was recorded during the sessions, and later transcribed and annotated. During each session, we intervened and went back to the documentation collected during the structured reflection process, in order to relate their discussion to related documents, where possible.

The interview transcripts underwent a thematic coding processes to elicit the core topics discussed. Based upon a grounded theory approach [30], the coding process was conducted by three members of the research team. Each member initially coded the transcripts individually and their list of codes were then compared, discussed, and adjusted until consensus was reached. In addition to the interview data, several other sources of data was provided by the Zooniverse team, including discussion boards for four Zooniverse projects, *talk pages* for 14 projects, as well as 26 Zooniverse-related blogs. This data represented a snapshot of the entire Zooniverse system from September 2013, encompassing data for 250,044 Zooniverse users, 50,995,591 completed tasks, and 650,243 talk pages. This data was used to obtain an overview of the Zooniverse platform, and by applying statistical measures related to user activity, we were able to compare the operation of the platform with the interview data and design claims.

Analytical Framework

We derived our analytical framework for successful citizen science projects from an earlier proposal centered around online communities by Kraut, Resnik et al [23]. Our design claims (DCs) mapped to a set of emergent topics which we organised into different categories based on their content and context (e.g., community structure, external communications, task design). These were identified through the thematic coding of the interview transcripts. Some of our findings correspond to existing guidelines from the literature [23]; others, we would argue, are unique to online citizen science communities, and are marked in the text with the keyword “New”.

RESULTS: KEY THEMES AND DESIGN CLAIMS

We present our analysis based on the structured reflection performed by the Zooniverse team and the thematically coded interviews. In collaboration with the Zooniverse team, we identified four themes corresponding to *Task Specificity*, *Community Development*, *Task Design* and *Public Relations and Engagement*. The choice of these themes pertained to the corresponding discussions and examples provided by the interviewees regarding (user) activity in a system, problems identified during system deployment, the solutions they adopted, or a behaviour that was unique to a system. The title and grouping of the design claims into these themes is primarily for structuring the results and discussion rather than being based upon an underlying theoretical premise, and in some cases a DC may span across themes.

Theme 1: Task Specificity

DC1: a) Citizen science participants want and need the ability to discuss aspects of projects and tasks. b) Standard message boards work well for small online citizen science communities, but do not scale up well; c) Lack of integration between community features and tasks creates overhead and wastes community effort.

During the launch of the first Zooniverse project in July 2007, there was no discussion space to accompany Galaxy Zoo. A groundswell of volunteers requested a forum, and so the researchers set up a standard, open-source, PHP Simple Machines Forum (SMF) in the early days of the project. PHP SMFs became the standard discussion tool for the first Zooniverse projects (Galaxy Zoo 2, Solar Stormwatch, Moon Zoo, and Old Weather) and provided a space for peer question-answering support, serendipitous collaboration, and social community building and sharing. The forums were low-cost to deploy, and low buy-in for new users, given the popularity of the forum interface in 2007.

As the forums expanded, it became clear that aspects of the PHP SMF design impeded their effective use for Zooniverse discussion. The linear, message-board format became difficult to navigate as the size of these forums grew. Moderators struggled to keep boards thematically consistent, with threads often ending up in different boards, duplicated, or with blended themes. Such problems, including fragmentation and duplicity mirror those well-known in many other large, online threaded discussion boards (e.g., [32]), and posed a serious challenge as some Galaxy Zoo boards expanded to over 5000 threads, collectively comprising over 650,000 posts. After several of the serendipitous discoveries were made, other problems such as the lack of integration between the forums and tasks became apparent. By early 2010, less than 10% of users were active in both classification and discussion.

In response, in August 2010 the Zooniverse team developed a bespoke forum known as *Talk*, which offered users object-specific discussion boards, in addition to more typical forum structure. *Talk* was built with with aim of promoting productive Zooniverse discussion, based on success stories from the PHP SMF fora. As described by a member of the Zooniverse team, the initial stage of integrating discussion into the community involved combining the forums with the task, which was then followed making it a straightforward process for a user to enter a discussion on a particular subject or topic. This was an attempt to make it more salient and in line with the task workflow [33]. The new forums were categorised by the most common themes identified in the original forums (*chat, help, science*), and as Kraut et al. pointed out, the division of the forum space into appropriate topics and categories helped reduce inactive spaces, improved navigation for the users, and reduced overheads for moderators. *Talk* was integrated into the workflow process of new Zooniverse projects (starting with the Milky Way Project in December 2010) in order to provide an in-line mechanism for users to communicate and share observations for further investigation. In September 2012 40% of users were active in both classification and discussion. The same figure held true in June 2014.

In August 2014 the original Galaxy Zoo forum was retired, and turned into a read-only archive. This was done at the request of the Galaxy Zoo forum participants who wanted to migrate to Talk, where more discussion was happening. Several of them were the same individuals who requested the original forum in 2007, and who helped moderate and keep it alive for so long. Thus, in addition to the existing design claims of discussion forums, we note that:

DC2 (New): Task workflows which encourage discussion facilitate citizen-led discovery.

Whilst the primary goal of a citizen science project is to complete the task within the pre-defined workflow, the Zooniverse experienced a number exciting *citizen-led discoveries* as a consequence of users going beyond the requirements of the task and asking questions about unusual objects within an observation.

Originally, the workflow of a Zooniverse project contained a series of tasks selected by the science team, which were devised to investigate a pre-selected set of problems. This workflow, the conventional path of most human computation systems, successfully yielded a majority of the findings for Zooniverse. However, the addition of discussion facilities opened a second pathway, which became apparent under a month after the Galaxy Zoo Forum first launched. By providing users with the tools to communicate, a user-driven process led to the discovery of a peculiarity object known as "Hanny's Voorwerp" [29]. This would ultimately mark the project's first citizen-initiated discovery.

The research following the discovery of the *Voorwerp* unfolded as it did because, being a rare astrophysical body quite unlike others, the science team quickly noticed it. In this case, citizen contributions were limited due to lack of access to other data sources, or telescopes for further follow-up or expertise. Moreover, being such an unusual form, most amateur scientists had never seen anything like it, and to validate the finding, the science team cross-referenced databases and tools that volunteers didn't have access to, running their own analyses before eventually applying for and scheduling time on telescopes with colleagues to gather more data.

In contrast, other serendipitous discoveries have been made due to the self-organised effort of volunteers. The Galaxy Zoo *Green Peas* [5, 6] discovery emerged because, whilst not common, pea galaxies were seen regularly enough that they were recognized by other citizens, which sparked a "pea hunt" amongst the self-titled "pea corps". According to a science team member, the discovery was initially overlooked as the science team were busy processing data being generated through the "main path", but also partially because it was believed the greenish appearance of the peas was merely artefactual of the imaging apparatus, as "green glitches" were quite common in the images.

Similar group search discoveries have been successful too. On Old Weather, a mass-tagging campaign took place to note the number of men in sick bay on board the various ships. This resulted an independent rediscovery of the 1918 Spanish Flu when huge spikes were seen in the sick bay timeliness. Similar a new type of emerging star-forming region has been identified by volunteers on the Milky Way Project after people began spotting "yellowballs" in the data and marked them using Talk. The discovery of a circumbinary planet on Planet Hunters [39] stands out from the rest in that the citizens derived their own astronomical models, generated from light curves autonomously without science team intervention. This example highlighted to the Zooniverse and its science teams that citizen volunteers could be true collaborators, and that citizen science systems served another important purpose, which was to bring users with varied capacities together around common problems of interest, across traditional organisational, national, and cultural boundaries.

In several of the examples (Voorwerp, yellow balls etc.), the initiating user simply asked for help in identifying an unknown object they saw. With the Peas discovery, meanwhile, the intention at the beginning was primarily social, commenting that she found things that "looked like peas". In the circumbinary planet findings, by comparison, the citizens already had a hypothesis about what they had found, and had conducted a partial analysis prior to first posting. Each of the citizen-led discoveries exhibit several underlying differences among the situations, yet they were shaped by a common constraint; immediate access to scientific expertise when progress stalls or problems arise, a problem that the Zooniverse overcame with the social mechanisms described in the next section.

Theme 2: Community Development

DC3: (a) Granting roles and privileges with experience can motivate contributors to effectively assume community leadership and maintenance roles. (b) Volunteer moderators can effectively filter issues requiring the science team's attention. Given that the science team responsible for a Zooniverse project are limited in resources, establishing a community which functions semi-autonomously and even supports the science team in running the project can be highly beneficial. Across all Zooniverse projects analysed, the volume of posts and threads on the discussion forums (usually over 300 posts per day) meant that it was not feasible for the scientists to monitor all discussions in order support all possible serendipitous leads. To overcome this, certain members of the community were promoted to a *Moderator* status, whose rolewas to filter and signal potential findings to the science team. However, in all four of the citizen-led discovery examples, at different stages of the process, the moderators lacked the necessary knowledge to answer the questions of their peers. However, when this situation occurred, the moderators were able to notify or consult the science team for their help.

DC4 (New): Timely support from science team members is essential to enable citizen-led discovery.

Based on their experiences with a number of citizen-led discoveries, the Zooniverse team came to the conclusion that the amount of effort that needs to be invested in supporting the community is relative to the rate at which progress occurs. Altthough moderators are helpful, the science team is still required to intervene when progress stalls or when unexpected issues arise in the line of scientific inquiry. They are also indispensable as discoveries eventually run their scourse and the only thing left to do is publish a result - something the public are not comfortable with at present.

The degree to which the science teams are involved in the discovery process varied amongst the examples provided. For the Voorwerp discovery, the science team took over the investigation shortly after the citizen pointed it out. In the other examples, however, there was more autonomous action by citizens; in the Peas case, for example, citizens self-organised a collection of samples and an informal analysis for approximately a year before the science team caught notice and took significant interest in their findings [6]. Alternatively, in the case of the convict worm and yellow balls, the science team intervened early and then immediately solicited to identify similar subjects. This was done because the science team did not know whether this was a one-off worm or common enough to constitute a distinct species. Finally, with the circumbinary planet discovery, the users conducted an entire hypothesis validation process, consisting of modelling and light curve analysis, using their own sets of tools.

Theme 3: Task Design

DC5 (New): Designing tasks to encourage* best guesses *avoids the* don't know *effort trap

One common request that the team intentionally did not honour was to add a *I don't know* or "Skip to next" button in task interfaces. The omission of such a button was a deliberate design decision based on early testing, which demonstrated that (as explained in a blog post [22]) the presence of such a button discouraged participants from attempting to figure out a *best guess* to the more challenging exercises. When present, it was too easy for participants just to press the button to see more subjects, essentially providing a motivation loophole that allowed the reward of access to new subjects without doing any work. Such a loophole reduced a major source of motivation, which was gaining access to previously unseen subjects. Not having a button, meanwhile, encouraged users to consider difficult cases and to submit a best guess. Such "best guesses" were ultimately useful to the science team, because they could be checked with other participants' best guesses, which would not have been captued without them. (In lieu of a "Don't know" button, the team added a "Discuss This" prompt, which allowed people to post about and discuss more difficult cases, further improving the likelihood of their disambiguation.)

DC6 (New): Multiple factors influence the perceptions of a project, including memorability/interestingness of subjects, task difficulty, speed, and amount of feedback provided.

The analysis of the user growth per project found that not all projects gained immediate uptake, and some were vastly more successful at securing long-term participation than others. As the team sought to identify the factors that influenced participants' perceptions the most through all the Zooniverse projects launched, several themes emerged. These were, first, the *interesting-ness of subject*, *speed and difficulty of task*, and related to these two, the *frequency and form of implicit reward*. Other factors, such as type of task, domain of origin, worthiness of cause (e.g., cancer research or deep space research), and source of data, did not generate conclusive findings. (One additional factor that emerged was media type - image-orientated tasks were much more likely to sustain participation than audio tasks.)

The first factor, *interestingness*, pertains to how likely the subjects being classified would be likely to be perceived to the general populace as interesting, or have aesthetic or emotional value, such as "beautiful and mysterious" photos of deep space, or the "cute" candid photos of animals of *Snapshot Serengeti*. This interestingness metric was also affected by *how often* interesting subjects came up amidst tasks with less interesting ones; specifically, some projects which sought to identify rare interesting objects which were only likely to come up once in a hundred or thousand subjects were perceived as less interesting than projects that had at least somewhat interesting subjects on every task.

Such insights led the Zooniverse team to re-design some of the tasks to avoid long stretches of monotonous subjects, that might influence participants to get bored and leave. To do so, for such rare-object search tasks, the team interspersed subjects in which objects were found by other users into the task queues of those who had not encountered such an interesting subject in a while. In *Worm Watch Lab*, for example, an algorithm was devised that would take subjects that were classified by at least one user to contain egg-laying events, and scheduled these into the queues of users who had not witnessed egg-laying events in their most recent classifications.

However, even monotonous sequences of subjects sustained participation if they could be performed quickly. The team's interpretation of this result was twofold, first, that with quick tasks it was easy to gain an accrued sense of accomplishment, and such a feeling could be sustained with less effort. This factor was used to explain the high levels of participation in projects such as *Ice Hunters* and *Moon Zoo*, which had long sequences of extremely similar-looking subjects, and therefore were rather monotonous but could be completed quickly. The second factor was that proposed was that such simple tasks had a lower barrier of engagement, and thus more people could contribute to them easily, e.g., without having to learn new skills, as well as being able to perform them casually without heightened concentration.

DC7 (New): Avoiding upfront tutorials in lieu of in-task UI guidance and interposed instructional tasks improves participant experience.

New users to citizen science platforms are unlikely to have the expertise necessary to complete tasks, especially when tasks are highly specialised within a particular domain [34]. For example, Spacewarps required the identification of rare celestial phenomena called gravitational lenses, while Snapshot Serengeti involved spotting and classifying animals particular to the Serengeti, including their precise species. A simple approach to this problem, and one that was initially taken in Zooniverse, was providing an instructional video for new participants when joining each project. However, adding such a video meant postponing actual task, and consuming valuable minutes of participants' attention that might potentially be better put to use if such tutorials could be avoided.

In particular, project analytics revealed that a significant proportion of users left within a minute or 90 seconds, and a video tutorial would have consumed the duration of their visit. Two strategies were devised in response to this need; the first was to re-design task interfaces to reduce the need for tutorials, by increasing *in situ* guidance. An example of this was the Snapshot Serengeti interface, which guided participants through a decision-tree like process to narrow down the species by identifying specific characteristics, such as the presence and kind of antlers/horns, size, colour and shape. However, a selection process of this nature would slow down experienced users who might immediately identify an animal they had seen before, the team introduced a second interaction path, a matrix of species designed to allow the species to be directly selected.

In addition to guided task interfaces, a second approach was to make tutorials short, interactive, and "feel" like real tasks. The benefit of doing this would be that participants would feel like they were contributing immediately, making them likely to stay longer. A particular variation that was adopted was one the interspersing of real tasks with gold standard tutorial tasks, an approach proposed in the crowdsourcing community [35]. The Zooniverse team found that this strategy was particularly appropriate for bringing new participants into tasks involving rare object searches, that is, in which participants would likely have to sift through a large number of subjects prior to encountering the sought phenomena, such as the aforementioned gravitational lenses in Spacewarps. In such tasks, interspersing gold standard true positives at a much higher hit rate than random helped not only teach individuals but also to keep them motivated to look for more.

DC8 (New): Periodic feedback can motivate continued participation

In addition to making tutorial stages feel like real tasks, the Zooniverse team found that interspersing diagnostic "gold standard" tasks periodically among the real tasks, to provide participants feedback about their performance, caused an increase in sustained participation. This complements earlier studies showing that participants' performance may increase, e.g., that participants will be more accurate and faster at completing tasks with such feedback [21]. Introducing "gold standard" tutorial tasks on several projects, including Galaxy Zoo, Planet Hunters, the Andromeda Project, and Space Warps also enabled first-time users to jump immediately into real tasks, even with no prior experience. The overwhelmingly large proportion of such users was reflected in the fact that an estimated 6,620,423 (or 15%) of the total task classifications came from such transient users who never ultimately signed up.

DC9 (New): Adding context to a task adds value and improves community engagement "Meta-data" around a subject became an important feature for the success of many Zooniverse projects. Take for instance the Old Weather project, it's purpose is to use meteorological readings taken by sea captains of 19th and 20th century ships to build long-term models of ocean climate. However, many of the ship logbook pages where measurements were taken also interleaved other information about events on ships, such as crew and cargo movements, ship damage, and so on, as well as the occasional draft personal letter from a sailor on the ship. Initially, the team intended to remove this *irrelevant* information; however, due to the difficulty in segmenting it out, it was decided to simply leave it in. This additional info was embraced by participants as clues to a partially-obscured history, and discussions grew on the forums about the significance of particular letters and activities on the ship. Participants exchanged thoughts on who the recipients of the letters may have been, the meanings of particular terminology, and gathered the histories of ships and crew members, drawing upon diverse information sources in their investigation.

While this kind of participation may have not directly benefited the original science task, it drove significant attention to the logs, and patched together interesting segments of a narrative history that may have not been otherwise given attention. In retrospect, the design of the Old Weather interface fostered this growth in several ways; first, an early decision to organise ship logs by ship, route, and date allowed users to reference logs by the same date, crew and route. By comparison, most other projects displayed subjects randomly based on classification need. Thus, preserving the context and provenance of information was seen to be sometimes extremely effective towards engaging interest from a wide and varied participant community.

Theme 4: Public Relations and Engagement

Strategies for publicising and gathering attention to citizen science projects across media channels, including traditional broadcast media, is often overlooked in smaller citizen science projects. However, the Zooniverse team found that, perhaps unsurprisingly, such a PR strategy was rather essential to driving substantial uptake. Cross-media PR played multiple roles, including bootstrapping fresh projects with a wider demographic than "digital natives" who are active on social media, but also to get users back who had been previously active and forgotten about the platform. The following design claims summarise PR and attention, and discusses the role of the first 24-hours after launch (project launch profiles) in determining and assessing success.

DC10 (New): Launch performance indicative of success; pre-launch PR important for recruiting new members and old

Performance during the launch of each Zooniverse project became seen, over time, as a valuable indicator of its likely future success, as well as an opportunity to reflect on and assess the project's pre-launch PR activities. This analysis included measuring active users on the site (down to per-minute granularity), identifying new participants, inferring, where possible, where each participant had come from, measuring the average time spent by each, discussion volume, and the social media traffic about each project, through the 24 hours after launch. Using such analysis, the team were able to devise a model of how to conduct successful launches using this analysis, which the team termed *launch campaigns*.

Several examples of successful launch campaigns included Snapshot Serengeti and Space Warps, which each experienced over 80,000 users during its first 24-hour "launch day". The Space Warps project experienced a initial surge of participants from other projects, in May 2013, with 10,000 people collectively contributing approximately 500,000 classifications in the its first 24-hour period. Participation in Space Warps continued beyond the immediate launch period, with more than 10,000 people unique visitors daily even three weeks later, a majority of whom were seasoned "Zooites". In January 2014, Space Warps was featured as part of BBC One's primetime "Stargazing Live" event and at its peak received 1,000,000 classifications in just an hour. The experience rendered the Zooniverse platform in-operational for about 3 minutes, as tens of thousands of existing Zooniverse users simultaneous attempted to reset their Zooniverse account password. Analysis revealed that a majority of the surge of participants consisted of existing Zooniverse users, who had learned of the new project via the launch announcement newsletters. Such observations led to an effort to synthesise effective "launch campaigns" that would both publicise new projects and time them in a way to gather the greatest number of initial users.

Coverage from traditional media outlets and online media aided the launch and growth of these projects. This included international media networks such as the BBC (on *The Sky At Night* and *Click*), widely-read scientific magazines including regular coverage in the "Citizen Science"' column of *Scientific American*, and featured articles in *National Geographic*. Such coverage regularly resulted in traffic spikes and influxes of new large numbers of new users, some of whom will continue to participate for weeks or months. In Snapshot Serengeti, the science team submitted 12 images to the BBC's *Camera-trap Photo of the Year* competition, based upon recommendations by users. This not only raised the profile of the project, but also had a positive effect on the active number of users, and the discussion activity within the forums.

DC11 (New): Citizen science communities are the most effective at leading their own social media campaigns

Early on, the Zooniverse team noticed that many participants were sharing on social media images of subjects they encountered during tasks, such as images of galaxies they thought were beautiful. Such posts sometimes generated small boosts in participation, as people discovered the project through their friends/followers' posts. A secondary effect of such posts was that, based on forum discussions, already active users were motivating by seeing such beautiful examples, driving them to find similar exemplary subjects to share by performing more tasks.

Such participant-driven initiatives can even sustain projects financially. An example was Snapshot Serengeti, which had attracted top participation levels and social media traffic. When funding for the project ran out, and requests for further funding were declined, the science team quickly turned to crowd-funding as an alternative to scientific institutions. This marked the first participant-funded citizen science campaign for Zooniverse. To make this happen, the platform's online community were mobilised by being told that the project would shut without their help; then, to facilitate spreading the word about the project, the team added a "meme this" function to allow participants to add meme-text to any image they encountered during a task. Turning Snapshot Serengeti subjects into memes was a relatively natural adaptation, as many internet memes already featured cute animals already. The result was a successful campaign that has indefinitely sustained the project to date.

DISCUSSION

Table 2 summarises the Design Claims. In this section, we draw connections to the Kraut et al's Design Claims for successful online communities [23], as well as comparisons to crowdsourcing design results and studies of other citizen science platforms.

Comparison with Online Communities

Several of the DCs derived in our analysis can be translated to support those for supporting effective online communities [23]. For instance, *giving individuals space to discuss and socialise* was seen in (DC1), while *granting specific roles and privileges to particular individuals* further encouraged these participants to fulfill their given roles (DC3). Support for the suggestion to *make easy-to-use tools for finding and tracking work* was seen in (DC2); the Talk forums of Zooniverse made it significantly easier to track subjects that needed further disambiguation by allowing subjects to be cross-referenced by id and grouped by hashtag, and this allowed the discussion volume to grow without the need for moderator involvement. Moreover, several of the insights pertaining to tutorial design, such as introducing gold standard tasks, coincide with the sugggestions towards enhancing intrinsic motivation, including *providing clear feedback and goals* (DC8). The idea of *quickly grabbing participants' attention and keeping it throughout* was supported by our DC7, the observation that upfront tutorial videos failed to grab participants' attention fast enough and thus drove them away before even being able to perform tasks at all. Pertaining to perverse incentives and *gaming the system*, support for this was behaviour was observed when the *Don't know* or *Skip* button was trialled; a seemingly innocous feature that would have led to a vast reduction in task completion levels.

However, there were other aspects of the DCs that we derived that did not see much support; for example, Kraut et al. propose that it is important to *emphasise the importance of contributions*; the Zoonivese team, meanwhile found that efforts to emphasise the importance of projects had little on resulting participation levels. For example, the Cell Slider, despite benefitting cancer research, was unable to sustain significant participation, likely to the overwhelming influence of the other factors, including difficulty of task, and lack of intrinsic appeal of subjects.

Comparison with Crowdsourcing

Several of the DCs also align well with recent observations from the literature around human computation and microtask

Theme	Design Claim	System Benefit
Task Specificity	*1. During the bootstrapping phase, focus on supporting and managing the community socially, rather than spending time developing bespoke community platforms*	Bootstrapping a Community
	2. Task workflows which encourage discussion facilitate citizen-led discovery	Finding new scientific discoveries
Community Development	*3. Granting roles and privileges with experience can motivate contributors to effectively assume community leadership and maintenance roles*	Engaging with users, supporting professional team
	4. Timely support from science team members is essential to enable citizen-led discovery	Supporting users, finding new scientific discoveries
Task Design	*5. Designing tasks to encourage best guesses avoids the dont know effort trap*	Obtaining new users
	6. Multiple factors influence the perceptions of a project, including memorability/interestingness of subjects, task difficulty, speed, and amount of feedback provided.	Retaining users
	7. In-task UI guidance and interposed instructional tasks improves participant experience, and increases the number of completed tasks	Supporting users, Improving task completion
	8. Providing users with periodic feedback can motivate continued participation	User retention
	9. Adding context to a task adds value and improves community engagement.	Improving user engagement, Finding new scientific discoveries
Public Relations and Engagement	*10. Launch performance indicative of success. Pre-launch PR important for recruiting new and previous participants*	Obtaining new users
	11. Citizen science communities are the most effective at leading their own social media campaigns	Obtaining new users

Table 2. ***Citizen science design*** **- Design patterns and anti-patterns based on an empirical analysis of the Zooniverse platform. Note: The themes used to group DCs together is for organizational purposes.**

crowdsourcing. Putting aside the different motives that drive participation, microtask designers are very concerned with the best ways to obtain accurate and timely crowd contributions. Any guide in this space will advise a requester, the person or organisation who solicits the help of the crowd, to document their tasks well (DC6), provide information about the ways in which the results will be used (DC8), as well as feedback (DC8), especially in those cases in which the work cannot be accepted [9]. Up-front instructions are more common in microtask crowdsourcing (DC7), though this has to do with the constrained design means a requester is allowed to use within existing microtask platforms. Studies of human computation, in particular around games with a purpose, have discussed similar task design challenges as in DC6. Designing a successful game experience greatly depends on the subject that is addressed [42] and on the way questions are being asked [27]. Rapid feedback cycles (DC8) and minimally invasive tutorials (DC7) have been extensively discussed in gamification literature [47].

Comparison with Other Citizen Science Projects

TO-DO: This is required as we said we'd do it in the rebuttal

Study Limitations

Pertaining to generalisability of our findings, despite the diversity of fields of inquiry represented by the various Zooniverse projects, Zooniverse remains but a single family of projects with common characteristics that may not necessarily pertain to other citizen science settings. For example, Zooniverse projects are all citizen data analysis projects, meaning that the design claims may not be directly relevant to data collection or problem-solving projects. Moreover, since Zooniverse's primary aim was *scientific outcomes and discovery*, this has very likely influenced the team's decision and perspective; other systems may have different, even multiple, priorities. Educating users, for instance, was not among the team's design goals, which was reflected in decisions such as reducing tutorials to minimum in-situ guidance to complete tasks. While effective at increasing users' task time, this had the effect that users did not readily gain skill in task performance over time, as evidenced by a study showing that experienced users rarely outperformed new ones.

Second, since we relied on structured reflection for our methodology, the limitations of this method also relate to this study. For example, reflection may suffer from various selection biases with respect to generated findings [15]. For example, recency, saliency and memory effects may make observations from recent projects seem more important to the team than ones from early Zooniverse projects, resulting in their being reported more prominently in this paper. In order to counter such effects, we encouraged the design team to re-visit their log notebooks from the beginning during the exercises.

A third limitation of our approach is that relied on the subjective perceived importance as agreed by members of the team, rather than any objective or measured quantities. Such subjective importance, gained through the experience of serially launching each of the projects, was, we felt, more meaningful than any simple quantitative measures taken either from any single project's analytics or in aggregate. However, due to the time and resource requirements of launching permutations of such science projects, the design claims have not been tested using any sort of controlled experiments. Therefore, the significance of the design claims stated, or their degree of interaction as factors influencing project success cannot be reliably extrapolated from this study.

CONCLUDING REMARKS AND FUTURE WORK

The Zooniverse project provides a particularly important case study for citizen science not only due to its breadth, longevity and success, but because it stands alone as an example where a single, small core team has been able to design, launch and conduct a large number of citizen science projects (37 to date). The opportunity to serially launch projects allowed the team to gain extensive experience, and to also to reflect upon, and carefully explore design options and strategy decisions throughout. Such exploration generated a huge variety of insights across aspects of task workflow design, interaction design, project launch and PR strategy strategies, project funding options, among others, of which we were only able to provide a summary of those deemed most important.

Above all, the team considered the most valuable insight gained related to the role of citizen scientists in a community like Zooniverse. Throughout Zooniverse's projects, the community consistently took on more roles and capabilities that had previously been expected to be the responsibility of supervisory science teams, such as supporting newcomers, debunking incorrect conclusions, to verifying claims. Perhaps most unexpectedly, citizens led inquiries that ultimately ended up as new discoveries, and even questioned the scientists' motives, sometimes coming up with their own investigations. In more than a few instances, participants took their investigations "off the board" and into their own tools to test hypothesis, bringing results and evidence back to the project for discussion.

The Zooniverse team suggests that such actions suggests one of the many avenues in which citizen science could – and indeed should, evolve – to get citizen scientists involved in all parts of the scientific process, including posing their own lines of enquiry. In particular, several science teams are currently working to open up access to essential core tools, analysis techniques, and data resources for several projects that have only been available to science teams. Beyond giving participants access to these tools, the Zooniverse team has launched an experiment called *Galaxy Zoo Quench* that gets citizens involved in the process of preparing scientific journal articles themselves. While still underway, the outcome of this project may see participants of citizen science projects become full and equal partners in the scientific process.

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