From Crowd to Community: A Survey of Online Community Features in Citizen Science Projects

Neal Reeves
University of Southampton
Southampton, UK
ntr1g09@soton.ac.uk

Ramine Tinati
University of Southampton
Southampton, UK
r.tinati@soton.ac.uk

Sergej Zerr
University of Southampton
Southampton, UK
s.zerr@soton.ac.uk

Elena Simperl
University of Southampton
Southampton, UK
e.simperl@soton.ac.uk

Max Van Kleek
University of Oxford
Oxford, UK
emax@cs.ox.ac.uk

ABSTRACT

Online citizen science projects have been increasingly used in a variety of disciplines and contexts to enable large-scale scientific research. The successes of such projects have encouraged the development of customisable platforms to enable anyone to run their own citizen science project. However, the process of designing and building a citizen science project remains complex, with projects requiring both human computation and social aspects to sustain user motivation and achieve project goals. In this paper, we conduct a systematic survey of 48 citizen science projects to identify common features and functionality. Supported by online community literature, we use structured walkthroughs to identify different mechanisms used to encourage volunteer contributions across four dimensions: task visibility, goals, feedback, and rewards. Our findings contribute to the ongoing discussion on citizen science design and the relationship between community and microtask design for achieving successful outcomes.

ACM Classification Keywords

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

Author Keywords

Citizen science, online communities, survey

INTRODUCTION

Online citizen science (CS) refers to a Web-based approach to involve members of the general public in scientific research on a volunteer basis [6, 48, 63]. CS projects are typically initiated and overseen by a team of professional scientists, who define the goals of the projects, assign tasks to volunteers, and feed the crowd-generated data into established scientific workflows. This emerging form of participatory research has been applied to a vast range of scenarios, including education, civic activism, and conservation [64], alongside a growing number of disciplines, from astrophysics and biology to social sciences and cultural heritage [37, 60].

Citizen science draws on methods and theories from the fields of Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW). As data-processing systems, they can be considered human-agent collectives [17] that use human cooperative work and crowd intelligence [33] to help professional scientists handle large amounts of raw data and advance their empirical work. As socio-technical systems, they foster an environment which enables loose-knit communities to form [41, 63], whose members communicate and collaborate using discussion forums [5, 60], chat rooms [59], or wikis [31].

The combination of human computation and sociality has shown to be effective in accomplishing scientific objectives, as well as in yielding unanticipated discoveries initiated by members of the community [60]. However, support for such communities varies significantly between different CS projects. Designing CS projects remains a complex process, requiring insight from a range of specialised areas and disciplines [3]. At the same time, the number of scientists involved can be small, lacking the prerequisite knowledge and expertise from areas such as HCI and CSCW, in order to design and run projects, and lack experience in successfully staging public engagement activities [60].

The motivation behind this paper is driven by the belief that design guidelines are crucial to simplifying this design process in citizen science projects. Whilst there has been focus on concentrating on factors such as participant activity levels as measure for successful CS initiatives [60], literature has begun to reveal the significance of community-specific project features, yet they still remains largely under-explored beyond a single project. Addressing this gap, this paper contains a study conducted investigating the features commonly used in 48 citizen science projects. We drew from an initial set of

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136 projects, and examined the supporting literature of online systems and publications accompanying them, and discuss their design choices in the context of previous guidelines on building successful online communities from the greater HCI and CSCW literature. Our study documents significant variations in the design of specific features, including rewards, performance feedback, goal setting, and seeking and managing contributions. It further identifies areas where CS projects are often incomplete or disregard best practises. We describe the online citizen science design space as a whole, to enable further research and innovation in this area.

Summary of Contributions

In this work we carried out a survey of online community design features in 48 citizen science projects, drawn from a large-scale meta study of over 150 scientific publications. To the best of our knowledge, this is the first work of this scale where a comprehensive set of CS project features are identified, extracted, and systematically analysed from the angle of online communities. Our research provides insights into the impact of those features on success of the underlying CS projects and specifically identifies community features as an essential component. Such insights are of particular benefit to those wishing to build successful CS projects with collaborative community aspects, highlighting key design considerations for overall project success.

BACKGROUND

In the past ten years there has been a rising interest in crowdsourcing approaches to scientific enquiry and experimentation. Such endeavours range from participatory sensing, to human computation projects in which volunteers collect, curate, and analyse scientific data. Our meta-analysis focuses on the extent to which existing citizen science projects have been able to build successful communities that contribute to their scientific aims. As argued in [60], the emergence of these communities has proven critical for the success of citizen science initiatives. Not only have such communities played a crucial role in several scientific discoveries, but they have also often helped new projects and sub-communities to form and grow. The section is divided into two parts: an introduction to citizen science, followed by an overview of previous work on online community design frameworks.

Online citizen science

Online citizen science draws upon theories and practice from several areas that have long been studied in HCI and CSCW, including human computation and crowdsourcing, online communities, and gamification. They have often been characterised as crowdsourced science [38], where professional scientists seek the help of large numbers of people to contribute to scientific research [15]. In its most common instance, a project would seek the help of volunteers to take on ‘microtasks’, collecting, curating, annotating, and analysing scientific data at a level that does not require specific knowledge or domain expertise [60]. Done effectively, such microtasks are dispatched and results are validated and aggregated in ways that allow project scientists to process large amounts of data accurately and at high speed [34]. One of the most prominent CS projects is *Galaxy Zoo*, which attracted more than 50,000 astronomy enthusiasts who classified hundreds of thousands of galaxies in just a few weeks. Such a task would have been extremely expensive and time-consuming if done by scientists alone or with the help of state-of-the-art object recognition software [28].

In a classification project such as *Galaxy Zoo*, participants are presented with an entity, which can be an image, graphs, an audio file, or a video, and then asked questions about that entity. For instance, users may be asked to identify features, map these features, catalogue entities, transcribe, or complete other microtasks [12]. Figure 1 shows a user interface from *Snapshot Serengeti*, from the *Zooniverse* platform. Here, the large image on the left corresponds to the entity which must be classified. The menu on the right lists the animal species to choose from. Microtasks may take various other forms besides classification. For example, in *eBird* volunteers submit observations of bird distributions in real-time. Some projects are minimally designed online spaces for people to upload or share their data, while others have more complex interfaces, sometimes in the form of games [8].

Despite involving large numbers of people, citizen science has historically targeted individual participants rather than groups or a larger community. It is thus uncommon for participants to be made aware of each others’ contributions, and microtasks are typically designed to be solved independently [34, 62]. Success is often measured in these terms, with metrics such as the number of registered users or the time it took to complete a certain goal being popularly stated measures[1]. Responses for each entity are typically aggregated and compared as a means of validation [21]. In the event that there is significant disparity between responses, an entity will be presented to a greater number of participants to gather further evidence.

Citizen Science projects vary in aim between those which seek to complete scientific research, with a focus on investigation, and those which seek to engage volunteers in science through education, training and raising awareness of issues such as conservation. This variation manifests in a number of characteristics, including the tasks requested of users, the technologies used in data collection and analysis and the settings, physical and virtual, in which these processes take place [63]. Just 16% of papers surveyed by Kullenberg and Kasperowski were found to have a scientific research output, reflecting the importance of these alternative educational, engagement goals [24]. At the same time, citizen science projects are associated with a relatively slow rate of publication [57].

Similarly, projects differ in the stages of the scientific process in which citizen volunteers are invited to participate. At their simplest, citizen science projects take the form of ’volunteered computing’ or use sensors, with volunteers used solely as a means to access processing power or distributed technology [14]. A more extreme form of citizen science is ’collaborative science’, an approach where volunteers assist in defining a

[1] Zooniverse blog, “Measuring success in citizen science projects, part 1: methods” – http://blog.zooniverse.org/2015/08/24/measuring-success-in-citizen-science-projects-part-1-methods/ [Accessed: 27 May 2016].

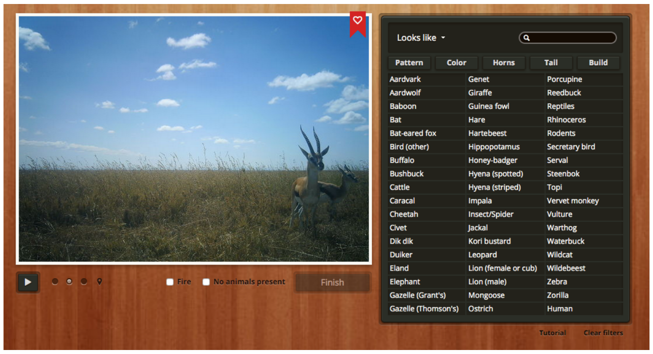

Figure 1. The classification interface in *Zooniverse*'s *Snapshot Serengeti* project asks participants to select the species of animals present within images from an extensive list.

research problem, gathering and analysing data and may even design studies, draw conclusions and disseminate findings [64, 14].

As the field of CS evolved, it became clear that introducing mechanisms for collaboration would be beneficial for the performance of the individual contributors and their long-term engagement with the project [60]. These mechanisms have taken diverse forms such as discussion forums [41], instant messaging services [20], or custom-built community spaces (for example, *Zooniverse*'s *Talk*). Such spaces allow for communication both between participants and between participants and the scientists responsible for each project. Since users are able to directly interact with one another, scientists are able to rely on the community to answer user queries, or to direct such queries to scientists when appropriate, rather than having to respond to queries on an individual basis [60]. There is evidence of communities gaining scientific knowledge through the use of discussion features [30]. Furthermore, several important serendipitous discoveries have grown out of these interactions: Hanny's Voorwerp and Green Peas in the context of *Galaxy Zoo*, [42, 5], the Circumbinary planet PH1b from *Planet Hunters* [47], and the new variety of nebula in *The Milky Way* project [19]. These discoveries have themselves resulted in publications in academic journals, written in conjunction with volunteers.

Online community design

Online communities are environments in which people gather to work towards common goals, socialise, share knowledge and resources, or communicate [23]. Such communities vary in size and may take diverse forms, although the majority of online communities take the form of textual discussion forums or email groups [25, 23]. Online citizen science projects are examples of online communities. A large community of volunteers must come together to enable completion of scientific goals, which often requires classifying tens of thousands of entities [60]. Online community design is therefore an important consideration when designing successful CS projects.

Online community design has been studied using various frameworks and analytical methods. Ren, Kraut, and Kiesler analysed theories of commitment with regard to online communities in order to identify design decisions which may lead to greater commitment [43]. The authors demonstrated that specific design decisions such as constraining or encouraging discussion among the community can influence group forming and commitment between community members and so influence the form that community participation takes.

Preece [39] explored the dimensions of sociability and usability in an effort to explore the concept of success in online communities. The resulting framework considers facets of sociability: volume of participation, reciprocity in contributions and benefits, quality of contributions, and participant behaviour. Usability dimensions are also key components of the framework: ease of use, speed of learning, measures of productivity, and user retention. These dimensions are of particular interest given our objective to identify features associated with online community success in CS projects.

Similarly, Iriberri, and Leroy analysed online communities within the framework of information systems life cycles to further explore the concept of success in online communities [16]. Dimensions evolve throughout the cyclical framework, from conception and purpose, to ensuring security and reliability during the creation process. Quality assurance and encouraging interaction become important during the growth phase, while mature communities must further focus on rewarding and encouraging interactions through events. Such a framework demonstrates the evolving nature of success and highlights the importance of early design decisions on later project outcomes.

Kraut et al. studied a diverse body of communities, ranging from crowdsourcing efforts such as *CAPTCHA* and *Mechanical Turk* to MMOs such as *World of Warcraft* [23]. Each of these communities was analysed based on empirical observations informed by key theories from the social sciences. They devised a total of 175 design claims, across five areas: encouraging contribution, encouraging commitment, regulating behaviour, dealing with newcomers and starting new communities. These design claims provide evidence-based guidelines for assessing online community success.

With regard to gamification, Mekler et al explored the impact of points and contextual framing of tasks on volunteers' intrinsic motivations and performance in an image annotation task [32]. Points were found to increase the quantity of tags generated, while framing had no significant effect on quantity. A combination of points and contextual framing was shown to have a significant effect on the time spent per tag, compared to just points or framing alone. Framing was associated with an increase in tag quality, an effect which was not seen with points. These findings suggest interface features can impact participant engagement and the effort expended by participants.

DATA AND METHODS

Our goal was to identify design principles and guidelines for improving CS projects by observing the interplay between current design decisions and success within project research outcomes. To this end, we consulted both the project platforms and research output from projects and the wider online citizen science literature. In order to do so, we began our analysis by identifying a selection of projects and documentation through a review of contemporary CS literature. Drawing from the success metrics identified during the literature review, we developed a framework of themes and success criteria affected by such themes within online community literature. This framework was used to conduct a survey of the selected projects, identifying mechanisms and affordances pertaining to each theme through a structured walkthrough process. The evidence basis determined through our literature review was further used to analyse the results of the survey process, to provide evidence for our findings from the wider literature and to distill design implications for further research moving forward.

Selecting Projects and Project Documentation

Initially, projects and project documentation were selected through a literature review designed to identify suitable CS projects, as well as potential issues pertaining to online communities. A search was conducted of four online repositories, selected to identify publications from a broad range of research disciplines (see Table 1). This search resulted in a total of 886 publications. The title and abstract of each were assessed to remove duplicates and publications deemed to be irrelevant (for example, offline CS systems). 152 publications were thus selected for further use.

Each publication was first analysed to identify potential projects for sampling. Projects were considered for inclusion if they contained at least one community feature (forum/wiki/discussion board/IM chat) and if it remained possible to register and contribute to the project. We excluded social media features due to the lack of input which social media users have on platform design and the difficulties in identifying official project social media channels.

After completing this process, we found that the majority of projects were no longer available, a factor which we partly attribute to the prolonged time it takes for citizen science data to reach publication (see, for example, [57]). Aware of the success that participants in citizen science systems have had in spreading awareness of systems (see, for example, [60]), we supplemented our sample with projects listed on *Wikipedia*, which features a well-maintained list of citizen science projects[2]. To ensure the validity of the information gathered, we visited each project URL to confirm the existence and suitability of the project.

We identified 136 projects in total, from which we selected 48 projects for further analysis according to the inclusion criteria. This list of projects was not intended to be exhaustive; while we made efforts to ensure the inclusion of a range of project microtask types and disciplines, the projects selected for inclusion are likely to be more popular than average, having drawn academic or volunteer interest. This was a deliberate choice, resulting form our desire to assess design decisions in projects making successful use of design features. Although we included multiple projects from the *Zooniverse* platform, we note that specific design decisions vary between these projects and we thus consider these projects individually. The full list of surveyed projects can be seen in the appendix.

Repository	Search terms	Results
JSTOR	ab:("online" + "citizen science") OR ab:("digital" + "citizen science") OR ab:("virtual" + "citizen science")	9
Google Scholar	"online citizen science" OR "virtual citizen science" OR "digital citizen science"	424
Scopus	TITLE-ABS-KEY ("online" + "citizen science") OR TITLE-ABS-KEY ("digital" + "citizen science") OR TITLE-ABS-KEY ("virtual" + "citizen science")	242
Web of Science	TOPIC:("online" + "citizen science") OR TOPIC:("digital" + "citizen science") OR Topic:("virtual" + "citizen science")	211

Table 1. Repositories and search terms used for the literature review.

Having identified a suitable sample of projects, we returned to our sample of literature and conducted a systematic review of each publication. We first removed publications deemed unsuitable for further use. This predominantly consisted of those publications which served only as data-releases of projects for which other, more informative publications were available. We also removed publications which referred only to projects deemed unsuitable for inclusion within our study. This generated a smaller sample of 115 items of literature. Each publication was reviewed in more detail to identify relevance to the surveyed projects, relevance to each of the four themes utilised within our online community framework and to determine success metrics and evaluation methods utilised within the literature.

Online Community Framework

To identify the extent to which projects adhered to online community design recommendations, we synthesised a framework of recommendations based on existing literature. We drew from the work of Kraut et al's *Building Successful Communities* [23] due to its application to a range of online communities and because it provides specific design claims for social and technical characteristics of successful online communities. These were considered alongside the frameworks described by Nov et al [36], Iriberri and Leroy [16], and Preece [39].

We first extracted design recommendations from the literature, identifying over 200 unique design recommendations. To ensure relevance to citizen science, we selected only recommendations which relate to ensuring high quantity and quality of contributions, as identified within the originating frameworks. Further, we selected only recommendations which we could observe from the systems alone; recommendations which would require consultation with participants were deemed beyond the scope of this project given the large number of systems involved.

Recommendations were finally grouped into a total of four broad themes:

[2]Wikipedia, "List of citizen science projects" – https://en.wikipedia.org/wiki/list_of_citizen_science_projects [Last Accessed: 27 May 2016]

- *Task visibility* – the ease with which participants can see and select microtasks and discussions requiring completion.
- *Goals* – the provision of challenges and targets for participants to achieve.
- *Feedback* – mechanisms for informing participants of the quantity or quality of submissions.
- *Rewards* – tangible or intangible awards given to participants for making contributions or achieving goals.

Structured Walkthroughs

To assess these themes within each of the selected projects, we conducted our survey by utilising a structured walkthrough-based approach. For each project, two researchers registered as participants and completed approximately ten classifications (or for data collection projects, assessed existing contributions), as well as observing community interactions. This was a four step process: Initially, each of the researchers separately registered and completed 10 classifications or other forms of contribution (evaluating existing contributions in data collection projects) within each of the 48 projects analysed within the study. During this initial step, each researcher produced a list of affordances, mechanisms and characteristics observed across all 48 projects. Following this, both researchers consulted with one another and compared the two lists, discussing points of contention and disagreement between the two lists, referring to the specific projects involved, in order to produce a common, unified list of mechanisms agreed upon by both researchers. Each researcher then separately returned to each of the projects, completing further contributions where necessary, in order to survey the number of times each of the mechanisms within the list was utilised within the sampled projects. Upon completion of this survey, the two researchers convened again to correct errors, discuss disagreement and produce a final list detailing the observed mechanisms and the number of occurences of the mechanism across the projects. In order to ensure accuracy and to prevent possible issues with the structured walkthrough approach, this list was then compared with evidence drawn from the literature review process, using relevant publications where available for each project, as well as project blogs and newsfeeds.

RESULTS AND ANALYSIS

In this section we report on our cross-sectional analysis of 48 citizen science projects by using the structured walkthrough, organised by the four themes: task visibility, goals, feedback, and rewards. For each theme, we identified a list of commonly occurring mechanisms, ordered by frequency within the sampled projects.

Task Visibility

Many of the identified mechanisms facilitated making tasks and discussions visible to users, such that volunteers could identify entities which require classification or discussion which requires participation (see Table 2). What follows is a synthesis of affordances based on our observed use of these mechanisms.

Automatic entity selection. In terms of microtask contributions, a significant proportion of platforms automatically selected entities for volunteers at the start of each session, providing little or no indication of how these entities were chosen behind the scenes. This way of assigning microtasks allows the science team to control the number of times each entity is classified by the crowd, while also ensuring completion. The *Zooniverse* platform uses an algorithm to control the number of classifications that each entity receives, although, in practice, entities may receive a greater number of classifications if the number of participants outweighs the number of available entities [51, 54]. *InstantWild* limits the available number of images for classification, with eight entities available for classification at any one time, while *EteRNA* allows contributions to each round of its *Cloud Laboratory* for a limited period of time only. Whilst still automated in task-selection, *EteRNA* allowed participants to select from all available entities by solving puzzles, with the ability to filter puzzles by recency, rewards, number of prior completions, and length. Similarly, *FoldIt* offered participants the opportunity to select puzzles, with several pre-existing groupings offered.

User-task selection. While automatic selection discourages large amounts of activity around particular entities, community-specific features may encourage a disproportionate amount of activity around a given task. Community-specific features tend to be facilitated with discussion boards, offering specific threads on a popular topic, particularly topics which have recently received attention from other volunteers. Participants are able to select threads and discussions freely, regardless of the number of discussions surrounding that entity, or time since the entity was uploaded. However, this does not extend to the microtask interface, which prevented the selection of specific entities in all but 4 of the most gamified projects such as *EteRNA* and *FoldIt*. In *EyeWire*, entity selection is a specific privilege, offered to a small number of participants as a reward for contributions of particular value (see *Rewards* for more detail).

Drawing attention. CS projects function by drawing volunteers' attention to entities requiring additional work, or to previously completed work as a learning experience. This was particularly common in community features, where threads or comments could be made clearly visible through the use of

Mechanism	# of projects
Notification of most recent activity	48
Free selection of discussion threads	47
Automatic Assignment of Entities	44
Sticky/pin function	43
Entity availability limited by classifications received	41
Follow function (by thread)	34
Completion percentage (by collection)	7
Dedicated area for entities in need of input	5
Customisable discussion feed	2
Entity availability limited by total number of entities	1
Task available for limited time	1
Follow function (by entity)	1

Table 2. Mechanisms which support task visibility.

Mechanism	# of projects
Classification challenges	18
Competitions	14
Opportunity for Rare Discoveries	6
Meta challenges (fundraising, attracting attention)	5
Survey (user voting for entity naming, etc.)	4

Table 3. Mechanisms which support goals.

sticky or pin functions, causing these threads to remain at the top of any lists of discussion threads. A similar mechanism was used in the task area of five projects, where a dedicated, clearly visible area was reserved to draw participant attention to entities in need of work. In community features, attention was almost always drawn to the most recent discussion contributions, as a proxy for those in need of contribution.

One area lacking from task visibility is the opportunity for volunteers to easily select entities which appeal to them. The 48 projects surveyed all offered participants relatively low levels of autonomy with regard to task visibility and task selection. In some cases projects would allow volunteers to select specific collections, such as logs from a given ship in *Old Weather*, or images of specific kingdoms and/or classes (e.g., fungi, birds and insects) in the *Notes from Nature* project. However, the difference between collections is largely thematic. In these cases, the burden of choice was placed on the user, rather than recommending collections based on participants' previous behaviour. *Phylo* and *FoldIt* allow volunteers to complete projects aimed at understanding specific diseases, rather than making use of the random assignment function, but this was again largely based on participants' choices rather than specific recommendations.

Goals

One effective method of motivating contributions identified within the literature concerns is to assign volunteers achievable goals. We identified a number of goal-setting mechanisms in various forms, as shown in Table 3, including the use of challenges and competitions to achieve a collective benefit, as well as individual benefits. Below are three forms of goals which these mechanisms afford.

Project-completeness goals. The most common form of goals observed, surrounded task completion and, in particular, the number of contributions received, with volunteers asked to increase their level of participation to meet these goals through *classification challenges*, coupled with *competitions* in 14 projects, predominantly on a temporary basis. The *Planet Hunters*, *SpaceWarps*, *Planet Four*, and *Higgs Hunters* projects all made use of three day challenges, asking volunteers to complete as many contributions as possible, to coincide with the BBC's *Stargazing Live* broadcast. These temporary goals lead to brief periods of extremely high rates of classification – the *SpaceWarps* project generated 6.5 million classifications in just 3 days, with a peak of 2,000 classifications per second [50]. After the completion of the challenge, contribution rates fall sharply – after 2 years, the three day challenge still accounted for the majority of contributions to the Planet Four project [46]. In the same manner, progress bars and completion counters are used to indicate the state of a project. The specific size and nature of a collection varies between projects. *Snapshot Serengeti* and *Verb Corner* divide entities into collections based on the period of time over which images were gathered, requiring completion of one season before another can be released. *Notes from Nature* runs concurrent collections, divided based on the focus of entities (e.g., plant, bird, insect) and thus the fields required for transcription. Other collections are more thematic – *Old Weather* divides log book pages into collections based on the ship from which the log book was taken. While for the most part these goals had specific deadlines, those mechanisms which served dual purposes lacked deadlines. Collection completion percentages, for example, function as goals and as a means of making tasks visible. Collection completion was not tied to specific deadlines – collections remained available and accessible until they generated sufficient numbers of classifications, at which point they were removed.

Milestone-driven goals. In some cases, challenges did not correspond to the completion of a collection, but to a set level of contribution, in the forms of milestones such as 'one million classifications'. Moon Mappers ran the 'Million Crater Challenge': setting a goal to achieve one million crater classifications across all participants between April the 20th and May the 5th, 2012. Major milestones offered rewards to individuals, as a further level of benefit. Although volunteers successfully completed over 100,000 classifications within the time-limit set for the challenge, the goal ultimately proved too challenging and it was not until October that the goal was finally reached. *EyeWire* has similarly hosted a number of month-long classification challenges. Participants are assigned a team at the beginning of the month and must score as many points as possible for their team throughout the month. *EyeWire* has also offered volunteers the chance to take place in a number of competitions at an individual level, with the aim of achieving the highest level of accuracy or the greatest number of classifications. Such tasks may involve scoring the highest number of points, making the most classifications or achieving the highest level of accuracy over the course of a week. Prizes are awarded to the winners (see Rewards below).

Community-based goals. The existence of goals aimed at community-feature participation is rare, with such goals almost exclusively taking the form of meta-challenges, aimed at aiding in the administration of a project or public awareness. These community-based goals were those most likely to affect the wider public, outside of the community of project participants. *Planet Hunters*, a project which aims to discover new planets, runs occasional competitions to allow volunteers to name new planetary candidates. Participation in the competition is entirely through community features, such as forums and survey forms. A similar community challenge, the *Snapshot Serengeti* 'Serengeti Selfies' campaign, aims to raise funds by asking participants to identify images of animals which appeared similar to photographic self-portraits in the 'selfie' style, for publication. Participants are asked to use the hashtag #selfie to identify such entities within the *Snapshot Serengeti* talk pages. This does not require engagement with the task-interface, though unlike Planet Hunters, there is nothing preventing the identification of such images

Mechanism	# of projects
Task-contingent feedback	29
Performance-contingent feedback	14
Performance-contingent feedback as numerical score	11
Gold Standards for performance-contingent feedback provision	7
Progress-bars for task-contingent feedback	7
Volunteer testing	5
Majority opinion-based performance-contingent feedback	4
Comments from science team	1

Table 4. Mechanisms which provide participants with feedback on individual contributions and overall project progress.

through the task interface and thus, does not exclude participation through task completion. When the *Snapshot Serengeti* project was faced with a reduction in funding, the team began a crowd-funding campaign. To publicise the campaign, a concurrent campaign was launched, where, while completing classifications, participants were encouraged to find amusing or interesting images and caption them, before sharing them via social media. The campaign successfully raised $36,324 and, at its peak, attracted 4,500 unique users to the *Snapshot Serengeti* project [22].

Feedback

In the systems observed, feedback serves a dual purpose, helping to ensure the validity of results, while also engaging volunteers through learning. Feedback provision mechanisms can broadly be divided into two groups: task-contingent, related to the number of completed tasks, or performance-contingent, related to the quality of contributions received [23]. Furthermore, feedback may be quantitative and systematic, through the task interface or discussion-based, through community features such as forum discussion.

Task-driven feedback. Task-contingent feedback was relatively common among the projects surveyed. The *SpaceWarps* project interface provided a counter which displays the number of images a user has viewed, as well as the number of potential gravitational lenses discovered. Such feedback may also be provided through comparison with other community members; *Herbaria@home* tracks all user contributions in a leaderboard, *Old Weather*'s rank function divides leaderboards into bands (ranks) where participants may progress by completing more classifications, *EteRNA*'s point system is a relatively unique feedback mechanism, with participants gaining points based on the difficulty of a puzzle, rather than solely the quality of their response. [55].

Performance-driven feedback. Explicit performance-driven feedback mechanisms were rarer among the projects surveyed. One relatively unique form of performance-contingent feedback occurred in *Phylo*; participants must pair nucleotides to build DNA sequences, with the task encouraging participants to match similarly coloured blocks. Participants are assigned stats based on how they perform in the task, which is then used to construct global leaderboards. In *EyeWire*, players received feedback as a point score, this score varied according to a number of factors, including the difficulty of a classification and the extent to which the classification differed from the average classification received [44]. Within the FoldIt project, puzzles were difficult and the research conducted was often complex for participants to understand. Volunteers therefore relied on these point scores to understand how their performance matches with what is expected from them and whether they were giving a useful or correct answer [11]. In *InstantWild*, participants saw an anonymised summary of the classifications received from other participants for a given entity. One inherent vulnerability in such a majority-based feedback mechanism as cited by the *EyeWire* team, however, is the danger of the majority opinion being incorrect, introducing the possibility that *EyeWire* classifications which are more correct than the majority will earn fewer points [44]. Performance-driven feedback has been shown to be highly effective in the EteRNA project, where participants modified their approach to puzzles according to results from laboratory experiments derived from the most effective submissions as judged by project scientists [9].

Performance-related feedback can also be combined with Gold Standard data; entities for which the 'correct' response is already known. By asking participants to classify these images, project administrators can compare responses to the pre-determined expert response in order to provide feedback to participants. These gold standards may be determined in a number of ways; *Stardust@home* makes use of an algorithm to classify gold standards. These gold standards, known as 'power movies' were periodically shown to participants, who received feedback by email (or within a report within the classification interface) detailing the number of power movies found, the number missed and a numerical score to describe their performance. *CosmoQuest* projects took a similar approach, using expert classified gold standards, with participants given a numerical score for their performance. *SpaceWarps* made use of simulations, with textual popups indicating correct/incorrect responses.

In 5 projects, performance-related feedback took the form of a test. *Stardust@home* prospective participants must pass a test to contribute to the project, by proving their ability to identify interstellar dust particles within entities. Participants are informed of correct and incorrect answers after completing the test. Each of the 4 *CosmoQuest* projects also tested volunteers, interspersing classifications with small tests, which provide feedback to participants. Unlike in *Stardust@home*, participants do not initially need to pass a test to contribute, but the tests encourage participants to repeat the tutorial process if a low score is earned.

Community feedback. In addition to feedback offered by site administrators, each of the surveyed projects offered participants the chance to provide written feedback in their community postings. A subset of projects explicitly encouraged this form of feedback; *Stardust@home* and *Herbaria@home* both featured long-running, 'stickied' forum threads with the purpose of allowing users to give and receive feedback on classifications. Even outside of these projects, feedback appears to be a common usage of discussion features, with *Zooniverse's Talk* interface allowing users to tag images with classifications, as a means of receiving feedback from other participants. The extent to which such feedback occurs is arguable, however – studies have demonstrated that in excess of 90% of discussion comments on *Zooniverse's Talk* platform have gathered no replies [30]. *Stardust@home* users received direct feedback from members of the *Stardust@home* science team. An area of the feedback page for each user contained space for comments from the science team in response to potential interstellar dust candidates. As with citizen-sourced feedback, however, this feedback remains rare. As of August 2016, only 88 potential dust candidates had been discovered since the project began and only 12 of these have feedback from members of the science team [56].

Measuring feedback. Task-contingent, quantity-based feedback was delivered exclusively in a quantitative form, with projects such as *SpaceWarps* and *Herbaria@home* keeping track of classifications in the form of a numerical score. Performance-contingent feedback, however, was offered in both quantitative and qualitative forms. Systems such as *Stardust@home*, *EyeWire* and *VerbCorner* kept track of numerical scores for participants as a form of feedback. Similarly, *CosmoQuest* participants received numerical scores after completing gold standard classifications, as a form of feedback. *SpaceWarps*, conversely, made use of written, qualitative pop-ups to provide feedback to participants on gold standard classifications. Where feedback was provided quantitatively, it took the form of point scores, overlapping with reward mechanisms. However, in two of these projects (*EyeWire* and *VerbCorner*), the method used for calculating scores was somewhat hidden from participants, to prevent efforts to game the system. This in turn makes ascertaining specific feedback, such as feedback on accuracy, relatively difficult, as accuracy-based scoring could be separated from other factors. In *EyeWire*, for example, accuracy was expressed by removing points from a user's score based on any perceived inaccuracy [44]. Participants did not receive a prompt indicating the number of points removed and the maximum score a user could receive varied between classification entities. As a result, while feedback calculation is systematic, the manner in which it is expressed to participants is less so.

Rewards

Contemporary literature argues that rewards encourage people to provide contributions. As Table 5 describes, across the surveyed projects, rewards can be supported through a variety of mechanisms. Rewards could be awarded based on the quantity of responses, as task-contingent rewards, or on the quality of responses, as performance-contingent rewards.

Mechanism	# of projects
Status rewards: Titles/Roles	41
Status rewards: Leaderboards	11
Points	11
Task-contingent rewards	11
Public announcement of achievements	7
Status rewards: Achievements/badges	5
Physical rewards	4
Unrevealed reward calculation factors	2
Privilege rewards: Additional tasks	2
Privilege rewards: Entity selection	1

Table 5. Mechanisms which reward participants and incentivise contributions.

Rewards within the surveyed projects took one of three key forms. Status rewards function by increasing a user's reputation, elevating that user's status by making other participants aware of his/her achievements. Privilege rewards allowed volunteers to access additional tools or task types, which other participants with lower levels of participation could not access. Physical rewards refer to prizes such as project merchandise.

Status rewards. The provision of reputation rewards was common across many projects. *EyeWire* participants who consistently performed at a high level of accuracy may receive a promotion to the role of *scout*. Scouts are identified within the *EyeWire* task interface by turquoise user names and through the word scout within their user profile. Roles were also granted within community features. Users of *Zooniverse*'s *Talk* were on occasion selected to serve as moderators, receiving the tag 'moderator' next to their posts. Leaderboards also served as a status reward, particularly for users in high positions. Leaderboard calculations varied between systems. Some leaderboard calculations were solely task-contingent, such as *Herbaria@home*, where users were ranked solely by the number of classifications they have made. Others were performance-contingent, as in the case of *EyeWire* and *Stardust@home*, where user rankings used points calculated based on accuracy. Leaderboards varied based on the time-scale over which ranks were calculated. *Herbaria@home* rankings described user contributions over the entire life of the project, while *Stardust@home* rankings were divided into seasons. *EyeWire* rankings were divided into three short-term categories: "today", "this week", and "this month.". *Old Weather* featured a rank system which served similarly to task-contingent leaderboards. As participants completed classifications within a given collection of entities, their number of classifications was compared with that of other users.

We found a number of platforms used badges/achievements to encourage contribution. These were awarded to participants for achieving particular goals within systems. Each collection within *Notes from Nature*, for example, had associated badges. These badges were entirely task-contingent; participants earned badges by completing a given number of classifications. Similarly, the *EyeWire* forum made use of task-contingent badges, with participants receiving badges for completing specific forum activities such as creating a post; editing a post or liking a post. The *EyeWire* classification task featured similar but more complex achievements. Achievement requirements are not advertised to participants and instead users discover achievements as they classify. Requirements may be task-contingent (such as completing a tutorial) or performance-contingent (such as earning a certain number of points or a certain level of accuracy.)

Privilege-driven rewards. Privilege rewards were often linked to status rewards; participants receive privileges either as an indication of their status within the community, or alongside a status reward. *EyeWire* roles, for example, had accompanying privileges, unlocked when users were promoted to a given role. Scouts were able to inspect any entity within a collection, rather than having to rely on automatic assignment. Similarly, moderators in *Zooniverse* talk were able to moderate discussions by carrying out activities such as deleting posts, something ordinary users are unable to do. In all cases, roles granted privileges in community-based activities. *EyeWire* role recipients received special indications in the live IM-style chat function and special chat tools. Similarly, *Zooniverse*'s moderators received special tools and capacities to moderate discussions, while receiving an indication of their moderator status. Other privilege rewards served independently of status rewards. The *VerbCorner* project allows users who have completed a certain number of contributions to unlock additional task types.

Physical rewards. Physical rewards were particularly rare among the projects surveyed. Only four systems offered physical rewards, in the form of physical prizes. Rather than using physical rewards for regular forms of participation, these rewards were only available temporarily and only for a very small number of users, who were responsible for particular achievements, or outright winners of a challenge. *Moon Mappers* offered up to 20 physical rewards during its Million Crater Challenge, for the user responsible for each 100,000th classification and ten randomly selected users. *EyeWire*, meanwhile, ran a week long *Camp EyeWire* event, with challenges based on accuracy and challenges unrelated to the project (such as a trivia quiz). Each challenge awarded both physical rewards (in the form of *EyeWire*-related merchandise) and bonus points to the winners and runner ups.

Reward exploitation. One issue posed by rewards is the danger of exploitation. With the introduction of rewards, some users shift their focus to achieve maximum rewards with minimum effort; completing tasks inaccurately or otherwise gaming the system. Certain projects aimed to counteract this by rewarding users on an unpredictable schedule and obfuscating reward criteria; a method employed by both *EyeWire* and *VerbCorner*. The points awarded to *EyeWire* users were calculated based on a number of dimensions, from accuracy to time. However, while spending more time on a classification was associated with a higher score, time-related points were capped at an unspecified value, making it difficult for users to accumulate points from delaying classifications. Further, an explanation of how points are calculated was kept relatively vague [44]. Similarly *VerbCorner* users received bonus points while contributing, but the requirements for bonus points were not publicised [2]. *LandscapeWatchSouthampton* features task-contingent rewards in the form of points. However, point scores are non-linear and users are not informed how points are calculated.

DISCUSSION

In this section, we discuss two areas which are relevant to the ongoing debates in citizen science and online community literature as identified during the literature review process: platform design for microtask- and community-orientated support, and factors to measure successful citizen science projects.

Microtask-Orientated vs Community-Orientated Features

Based on our structured walkthrough of 48 citizen science projects, we have observed common features and design patterns across the projects. By framing our analysis around 4 themes, namely: task visibility, goals, rewards, and feedback, we observed a spectrum of features pertaining to the management of two critical components; the task, and the community.

We have structured our results around four separate themes for purposes of clarity, and to reflect existing online community framework literature. It is however clear, that these four themes are highly coupled with each other. Each component is integral not only to ensuring user engagement, but also to improving and maintaining consistency and accurate results. Approaches to goal-setting and reward provision are closely linked to the way in which microtasks are presented to participants. Furthermore, it is these goals and rewards which determine the type of feedback which should be provided to users, as well as the form this feedback should take.

In light of our observations and analysis, our findings suggest a closer connection between microtask and community features than has previously been considered. While rewards predominantly result from engagement with and completion of project microtasks, their value predominantly results from community prestige: leaderboards, badges and titles, for example. In some cases, titles and roles were granted, conferring community-related privileges (for example, the opportunity to moderate conversations, or to interact with users requiring guidance), based on microtask contributions. Goals attached to deadlines, for example, are attached to the completion of classifications and even meta challenges, aimed to maintain projects through community action may result in increased rates of microtask completion. Furthermore, interaction with fellow community members fulfils an important role, particularly in those projects which lack other feedback mechanisms.

In the systems we have studied, the design of the microtask, and the features which provide the interaction layer are vastly different. As the analysis has revealed, the various systems provide different levels of interaction with the microtask component of the citizen science project. Automatic microtask selection was a dominant feature in many of the projects, despite existing literature suggesting that participant performance may be increased when manual selection of microtasks are possible [23].

With regard to automatic selection, by identifying user strengths, it is proposed that projects could be made more efficient, with users shown entities which are related to these strengths, rather than random entities. Similarly, by understanding appealing classification entities, users could be offered a greater proportion of entities which interest them, with an aim of ensuring they remain motivated throughout the life of the project. Within the *Zooniverse* platform, there have been proposals and experiments conducted to implement features surrounding this area, along 3 dimensions: user ability, user interest and maximising user motivation [27], however due to the complexity of microtask-assignment, the algorithm used by the *Zooniverse* makes use of random assignment of entities [51]. Furthermore, there is a trade-off here: allowing participants to select their own tasks has the danger that classifications become disproportionate, and certain resources are never selected. An alternative to this would be to design the task selection as a mix of automation and manual selection. EteRNA is a good example of such a workflow, where participants can select tasks from a pool of pre-assigned resources.

As our analysis revealed, community-supported task selection was not favoured, and was not used (as the main mechanism) by any of the projects. Existing studies have shown projects which have strong communities tend to be more successful, generating more classifications, and taking less time to complete project goals[30, 60]. Whilst we found projects such as *EyeWire* enabling users and admins to recommend specific tasks to work on individually and via teamplay mode (this is not the main approach, random assignment is dominant), there is very little efforts towards letting the crowd assign the tasks, or at least recommending tasks for participants to complete. We also see this highly relevant to the lack of user-operated tools, which provide control and power to the user with respects to completing tasks, or more generally, interacting with the system. In studies of non citizen science online communities, user tools have been shown to improve overall success of the platform [23]. For citizen science, tools to enable users to monitor and track their work could enable new modes of operation, facilitating the discovery of tasks which may be relevant to a player, clustering like-minded players based on their skills and past classification history, or to help the serendipitous discovery of scientific knowledge [60]. Moreover, such tools can also be coupled with the community, allowing collaborative task workflows to emerge.

Closely related to the task visibility is the implementation and integration of feedback mechanisms to provide participants with guidance and reassurance on their contributions. As our analysis reveals, feedback mechanisms were not a common feature, despite users requesting such features (e.g. *Galazy Zoo* users [40]). Roy et al., [45] note the importance of feedback mechanisms for maintaining user engagement and motivation in citizen science initiatives. However, providing feedback is complex and often difficult as many of the tasks do not have a correct answer [61]. Overcoming the difficulty of providing timely and meaningful feedback can be achieved via a number of methods beyond automated methods; as Kraut et al. [23] describe, community-driven, discussion based feedback is often a suitable method when it is difficult to obtain repeatable quantitative systematic feedback. As a number of projects have shown, community-driven feedback can yield highly valuable results, such as unanticipated scientific findings [5]), or in projects such as *EyeWire*, where features like the real-time chat interface, have helped harness the expertise and knowledge of long-term members to encourage newcomers, and facilitate the crowdsourced answering of players.

Goals and rewards are also major components to be considered for a citizen science project. These depend on the type of task, and more importantly, the decisions made at the initial stage of designing the platform. Considering the projects reviewed, the use of gamification elements, such as leaderboards, points, badges, and status are important design decisions that have to be made, which have implications for the future of the projects marketing, community management, and maintenance (socially and technically). These decisions also have implications on the community component of a project; for instance, in *EyeWire* [59, 58], competitive elements encourage participation. Such phenomenon has been observed elsewhere in other online community platforms [65], where up to three times as many contributions were found when suitable goals and rewards were used. Given the strong intrinsic motivations to participate [42, 58], designing these features with a strong emphasis towards community engagement is beneficial to a projects success. Even where gamification and competition is integral to the design of the platform (c.f. *EyeWire*), participants use their elevated-privileges to further support their fellow participants.

Success factors for Citizen Science

Citizen science is a diverse and growing field, with a range of task types and scientific goals. Perhaps because of this, there is currently no universally accepted set of criteria for defining project success. Those studies which have attempted to define such criteria generally apply to a given project, platform or context, such as the work of Cox et al. and Graham et al., both of which utilise *Zooniverse* as a basis for success criteria [7, 13]. To determine success metrics, we identified common measures discussed within CS literature, as identified during our literature review, which may serve as a basis for such success metrics. While there is no commonly accepted framework, we believe these measures describe common aims across citizen science projects.

Engagement (i) – Number of people reached

One commonly cited statistic within CS literature concerns the number of users which a given project has engaged and who have contributed to the project, both through microtask and community contributions. Within our survey, *goals* and *rewards* are the mechanisms most likely to achieve such impact, although this metric was not a significant factor in the selection of these themes. The successful *Save Snapshot Serengeti* campaign achieved a significant impact, reaching thousands of users a day and even the general public, by setting goals for users to share project materials [22]. While goals and rewards are common in online CS projects, we notice a focus on microtask completion, rather than community engagement goals and rewards. We suggest that increased use of goal setting, particularly community-based goals, as well as increased use of community-based rewards will lead to increased project engagement. In particular, meta-campaigns and social media sharing campaigns are a simple, yet effective method for reaching people outside of the community of participants [60].

Engagement (ii) – Number of contributions received

A further measure of successful engagement is the number of classifications recieved by a project. Any CS project must receive a minimum number of classifications to meet its goal and facilitate scientific research. Moreover, increasing the volume of contributions received by increasing engagement may confer further advantages, such as allowing for increased accuracy through the aggregation of results (see for example: [54]).

Similarly, contributions to discussion platforms can serve as a second path to scientific discoveries (see for example: [5]). Our results show that the task visibility mechanisms used support microtask completion, but are less effective for community contributions. This is reflected in the large percentage (>90%) of *Zooniverse Talk* comments which lack responses [30]. It is our view that increased use of community-related task visibility mechanisms and ensuring equal rewards for both microtask and community contribution will increase the number of contributions received within community features, increasing volunteer engagement. Furthermore, effective use of feedback can positively contribute to the number of contributions received from volunteers in VCS projects [1, 52].

Accuracy and Quality – Validity of results gained

In order for CS results to be used for scientific research, they must be accurate. CS projects must therefore positively reinforce correct contributions from volunteers. Within our survey, both *feedback* and *rewards* were identified as playing the greatest role in allowing project design teams to ensure the accuracy of contributions, not only ensuring that results are corrected in real time, but also correcting participants to ensure the accuracy of future contributions. Feedback and reward mechanisms are popular components in the CS projects surveyed, with a general focus on task-contingent, quantity-based feedback. Performance-contingent feedback, however, was less common. Instead of focusing solely on quantity of microtasks completed, we recommend shifting these mechanisms to assess quality of contributions, as a means of improving project accuracy. We note that projects must often assess accuracy before publishing data, by comparison with gold standards or through calculation of other metrics (see for example: [54, 28]). A simple mechanism for providing performance-based feedback would be to carry out such a process earlier, in tandem with volunteer contributions, allowing for the results to be shared with volunteers on an ongoing basis, in the form of performance-based feedback. While generating such feedback can be complex, we note that even relatively simple feedback such as points can be a useful measure for volunteers when determining how well they are performing and when attempting to improve [11]. Wider community feedback can also be an important source of increased accuracy. The project iSpotNature, which relies exclusively on community-derived feedback, identified increases in the accuracy of metadata attached to submissions in 57% of cases [49]. Conversely, such an approach alone may be insufficient to ensure accuracy - despite the relatively high overall accuracy (96.6%) achieved by the Snapshot Serengeti project, which also features only community-based feedback, certain species feature much lower accuracy rates, in cases as low as 33%, with rarer species more likely to result in false positives [54]. We observe that determining the effectiveness of such feedback is further complicated by the difficulties in receiving responses identified within project literature (see for example: [30, 60]).

Design Recommendations

Designing online citizen science projects is a complex process, with individual design decisions impacting a number of factors, including volunteer engagement and motivations, data quantity and quality and the research outcomes of a project.

In terms of task visibility, we identified 6 mechanisms among the surveyed projects for identifying discussions in need of contributions. However, in contrast to task-related mechanisms, these mechanisms did not ensure equal attention is given to each task, as these mechanisms provided little support for volunteers in identifying those threads most in need of attention. The most common mechanism, *notification of most recent activity* is unsuited for the asynchronous nature of many of the platforms identified, requiring volunteers to observe the platform around the time a post is made to be able to see it. Similarly, while *free selection of discussion threads* allows volunteers to find discussions of interest to themselves, the large number of posts involved in many projects increases the likelihood that some posts will go unseen. In just 7 months, Snapshot Serengeti generated 39,250 discussion posts, while SpaceWarps generated 20,978 posts in 2 months [30]. Other mechanisms require users to specifically seek out threads and subscribe in order to see further responses.

As an alternative, we propose enabling volunteers to order posts according to the number of replies that a post has received. Evidence from both Zooniverse and FoldIt suggests that volunteers fulfil specific roles when engaging in community discussions, including answering and contributing to questions and open discussions [9, 59]. By simplifying the process of finding such discussions, we believe that volunteers will be able to reduce thread response-times and the number of unanswered threads with minimal input from project scientists.

Setting suitable goals for challenges is a difficult process. If goals are too simple or deemed unachievable by volunteers, then they can negatively impact the number of classifications volunteers submit [26, 29]. Levels of engagement can be extremely unpredictable, as in the case of the Andromeda Project, a Zooniverse citizen science project where volunteers successfully completed over a million classifications in just two weeks, a feat that was expected to take two months [18].

We therefore propose the use of meta-challenges, surveys and community-based competitions, instead of challenges explicitly linked to task-completion. These challenges have shown to be effective in attracting volunteers to projects and increasing the completion of task classifications. Furthermore, such challenges can provide fund raising opportunities, gathering resources for projects while at the same time not requiring the heavier time or money investments that may be associated with classification challenges. This is particularly valuable given that task-based challenges were often coupled with physical prizes and that successful use of such challenges requires time investment and careful monitoring from community moderators and design teams [23].

Differing forms of feedback serve different, but equally important roles, in positively re-enforcing volunteer behaviour. Performance-contingent feedback is essential for complex tasks, allowing volunteers to identify whether they are contributing correctly [11]. Task-contingent feedback is equally valuable, in reassuring volunteers that their contributions are valued and used by scientists [52]. Furthermore, both forms of feedback serve to reinforce the function of goals, allowing volunteers to follow their progress with respect to other volunteers and goal deadlines [23]. Feedback is particularly valuable in VCS, where doubt has been cast on the use of tutorials as a means of training volunteers. Starr et al note that video-based, online tutorials can be as effective as in person training for citizen science tasks [53]. However, Newman et al note that such training is unsuitable for more complex skills and tools, which volunteers struggle with even after completing the tutorial process [35]. This is further exacerbated by the unwillingness of many volunteers to complete the tutorial process, reducing the size of the community [10], or necessitating the use of non-compulsory tutorials [60].

We recommend that projects deliver both task- and performance-contingent feedback. Task-contingent feedback should be delivered predominantly through automated calculations, providing volunteers with dashboard-style statistics on project completion, or with more competitive projects, through leaderboards and point calculations. This allows volunteers to receive updates in real-time, while also reducing the overall workload for project scientists. Performance-contingent feedback is more complex, as noted, due to the lack of 'correct' responses. We suggest a trade-off between the accuracy of feedback and the level of workload required of project scientists. In its simplest, but least accurate form, projects can compare responses with the majority opinion. More accurate feedback can be generated by creating a gold-standard set of images with which volunteers responses can be compared, but such an approach requires the investment of time before projects launch. Furthermore, as the number of entities within a project increases, further attention is required from project scientists if the level of feedback offered is to remain consistent.

As with goals, rewards have the potential to negatively impact volunteer behaviour, reducing motivation and encouraging users to game the system to receive maximum rewards from minimum effort [10, 23]. Such effects are associated with specific forms of reward: physical rewards and task-contingent reward structures are more likely to encourage such behaviour than status rewards, particularly for those who are less invested in the community [23].

We therefore propose that rewards should be performance-contingent, encouraging volunteers to create quality submissions, rather than a large quantity of lower quality submissions. In this way, rewards can serve as a further feedback mechanism, re-enforcing positive behaviour and allowing volunteers to monitor the quality of their own contributions. Status rewards should be utilised to reduce the likelihood of negative behaviours, while also reducing the resources required to produce rewards - physical rewards are likely to be costly, which is problematic for VCS projects. By monitoring the status awarded to volunteers, project scientists can identify those volunteers who are most dedicated to the project and confer on them specific roles such as *moderator*. Evidence from Zooniverse's Talk system suggests that volunteer moderators can be highly effective in identifying and flagging topics which require attention from science teams, reducing the effort required of project scientists while helping to ensure that discussions do not go unanswered [60].

Limitations

The facets discussed within this work are only a small subset of the vast number of dimensions for online community success discussed within the literature. While we have selected those deemed most salient, it is clear that many other factors must be considered in designing and building successful community-based online citizen science projects. One such area is the implementation of gamification. A number of gamified aspects have been identified within this survey, such as user motivation, leaderboards, point scores, badges, and ranks. This is particularly significant within the Games With A Purpose such as *EteRNA*, *Phylo* and *FoldIt*. While our work has focused on the use of online community mechanisms, other studies suggest gamification may also play a key role. Mekler has demonstrated that gamification elements affect the level and form which engagement in CS takes, while Bowser et al suggest gamification may be key to attracting demographics such as millenials to CS projects [32, 4].

We also are aware of the limitations pertaining to identifying impacts on project success. Due to the observational methodology utilised within this work, it is not possible to directly quantify the effect that the use or lack of a given mechanism has had on particular success metrics. However, identifying quantitative measures for certain design decisions is also a difficult process even were a differing methodology to be employed – particularly in citizen science, where a number of compounding factors such as volunteer interests may exist. We believe this is an area for further research, although such research will need to consider precise measures for the effects of such decisions.

RELATED WORK

In this section we discuss related work which has contributed to our research. We highlight the contributions that these studies have made to the research process and outlining the ways in which our work builds on and otherwise deviates from the existing literature.

A similar study concerning factors impacting the quality and quantity of contributions to online citizen science projects was conducted by Nov et al [36]. The authors looked at 3 systems, *Stardust@home, The Citizen Weather Observer Program (CWOP) and The Berkeley Open Infrastructure for Network Computing (BOINC)*. In particular, the analysis conducted by Nov et al concentrated on the impact of individual motivational factors and forms of motivation on levels of contribution and the quality of contribution, in terms of Collective, Norm-Oriented and Intrinsic Motives, as well as Reputation. While all four motives were found affect the quantity of contributions received, only collective motives and reputation were found to positively influence the quality of submissions. We note the similar questions raised by this research and utilised this study in the literature review which formed the evidence basis for the analysis outlined within the discussion section of this paper. However, our research differs also differs greatly from that of Nov et al, drawing on a larger selection and wider range of projects. Furthermore, our work has an online communities and design focus, informed by the design decisions underlying the projects studied and the wider online community and citizen science research informing and describing the results of such decision.

Kullenberg and Kasperowski conducted a large-scale analysis of citizen science literature, drawn from the Web of Science database [24]. This analysis drew on two datasets of publications, one comprised of 1935 items and one of 633 items, in order to conceptualise citizen science and the processes and aims associated with it. This work provided important insights into the literature review process used, including the keywords selected and identifying methods for removing irrelevant papers, false positives and negatives and other outliers generated through the search methods used. While our work shares some similarities with that of Kullenberg and Kasperowski, we drew on a comparatively smaller, but more varied body of literature, using a larger range of databases. In addition, our search terms focused exclusively on online citizen science projects, in contrast with the more general focus of the search conducted by Kullenberg and Kasperowski.

CONCLUSIONS

In this paper we performed a systematic structured walk-through of 48 citizen science projects to investigate common features implemented in such platforms. Based on our analysis, we identified a number of relevant design claims for motivating user contributions, across the themes of task visibility, goals, feedback, and rewards.

Online citizen science projects serve as a unique form of online community and an understanding of such systems continues to emerge. As with all online communities, citizen science projects face challenges with regard to encouraging contributions from users, both in the form of the microtask component of a project, and community participation. Citizen science communities face further unique challenges with regard to ensuring the validity of data and justifying the use of a crowd-sourced, citizen science-based approach.

Our analysis has demonstrated a close connection between task and community aspects of CS projects, previously considered to be separate dimensions. We have further identified links between the use of online community design principles and CS project success metrics, although we recommend that further consideration should be given to how design decisions and the inclusion of features may impact these metrics. One key area for future work will be exploring quantitative measures for specific design decisions, to allow for more informed decision making in CS design.

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APPENDIX

List of Projects Surveyed

Project Name	Project URL	Community Features
Annotate	https://anno.tate.org.uk	Talk (Zooniverse Custom Platform)
Asteroid Mappers	https://cosmoquest.org/?application=vesta_mappers/	Discussion Board Forum
Asteroid Zoo	http://www.asteroidzoo.org	Talk (Zooniverse Custom Platform)
Bug Guide	http://bugguide.net/	Discussion Board Forum
Chicago Wildlife Watch	http://www.chicagowildlifewatch.org	Talk (Zooniverse Custom Platform)
Chimp and See	http://www.chimpandsee.org	Talk (Zooniverse Custom Platform)
Condor Watch	http://www.condorwatch.org	Talk (Zooniverse Custom Platform)
Cyclone Centre	http://www.cyclonecenter.org	Talk (Zooniverse Custom Platform)
Disk Detective	http://www.diskdetective.org	Talk (Zooniverse Custom Platform)
EteRNA	http://www.eternagame.org	Live Instant Messenger Chat, Discussion Board Forum, Wiki
EyeWire	http://eyewire.org/	Live Instant Messenger Chat, Discussion Board Forum, Wiki
Floating Forests	http://www.floatingforests.org	Talk (Zooniverse Custom Platform)
FoldIt	http://fold.it/portal/	Discussion Board Forum, Wiki
Fossil Finder	http://www.zooniverse.org/projects/adrianevans/fossil-finder/	Talk (Zooniverse Custom Platform)
Galaxy Zoo	http://www.galaxyzoo.org	Talk (Zooniverse Custom Platform)
Galaxy Zoo Bar Lengths	http://www.zooniverse.org/projects/vrooje/galaxy-zoo-bar-lengths/	Talk (Zooniverse Custom Platform)
Herbaria@Home	http://herbariaunited.org/atHome/	Discussion Board Forum
Higgs Hunters	http://www.higgshunters.org	Talk (Zooniverse Custom Platform)
Instant Wild	http://www.edgeofexistence.org/instantwild/	Comment Listing
iSpotNature	http://www.ispotnature.org	Discussion Board Forum
Landscape Watch Hampshire	http://www.hampshire.landscapewatch.com/	Discussion Board Forum
Mars Mappers	https://cosmoquest.org/?application=mars_simply_craters	Discussion Board Forum
Mercury Mappers	https://cosmoquest.org/projects/mercury_mappers	Discussion Board Forum
Milky Way Project	http://www.milkywayproject.org/	Talk (Zooniverse Custom Platform)
Moon Mappers	https://cosmoquest.org/?application=simply_craters	Discussion Board Forum
Notes From Nature	http://www.notesfromnature.org	Talk (Zooniverse Custom Platform)
Old Weather	http://www.oldweather.org	Discussion Board Forum
Operation War Diary	http://www.operationwardiary.org	Talk (Zooniverse Custom Platform)
Orchid Observers	http://www.orchidobservers.org	Talk (Zooniverse Custom Platform)
Penguin Watch	http://www.penguinwatch.org	Talk (Zooniverse Custom Platform)
Phylo	http://phylo.cs.mcgill.ca/	Discussion Board Forum
Planet Four	http://www.planetfour.org	Talk (Zooniverse Custom Platform)
Planet Four: Terrains	http://www.zooniverse.org/projects/mschwamb/planet-four-terrains/	Talk (Zooniverse Custom Platform)
Planet Hunters	http://www.planethunters.org	Talk (Zooniverse Custom Platform)
Plankton Portal	http://planktonportal.org/	Talk (Zooniverse Custom Platform)
Radio Galaxy Zoo	http://radio.galaxyzoo.org	Talk (Zooniverse Custom Platform)
Science Gossip	http://www.sciencegossip.org	Talk (Zooniverse Custom Platform)
Season Spotter Image Marking	http://www.zooniverse.org/projects/kosmala/season-spotter-image-marking	Talk (Zooniverse Custom Platform)
Season Spotter Questions	http://www.zooniverse.org/projects/kosmala/season-spotter-questions	Talk (Zooniverse Custom Platform)
Snapshot Serengeti	http://snapshotserengeti.org/	Talk (Zooniverse Custom Platform)
SpaceWarps	http://spacewarps.org/	Talk (Zooniverse Custom Platform)
Stardust@Home	http://stardustathome.ssl.berkeley.edu/	Discussion Board Forum
Sunspotter	http://www.sunspotter.org	Talk (Zooniverse Custom Platform)
Verb Corner	http://gameswithwords.org/VerbCorner	Discussion Board Forum
Whales As Individuals	http://www.zooniverse.org/projects/tedcheese/whales-as-individuals	Talk (Zooniverse Custom Platform)
Wildcam Gorongosa	http://www.wildcamgorongosa.org	Talk (Zooniverse Custom Platform)
Wildebeest Watch	http://www.zooniverse.org/projects/aliburchard/wildebeest-watch/	Talk (Zooniverse Custom Platform)
Worm Watch Lab	http://www.wormwatchlab.org	Talk (Zooniverse Custom Platform)