Is Virtual Citizen Science A Game?

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The use of game elements within virtual citizen science is increasingly common, promising to bring increased user activity, motivation, and engagement to large-scale scientific projects. However, there is an ongoing debate about whether or not gamifying systems such as these is actually an effective means by which to increase motivation and engagement in the long term. While gamification itself is receiving a large amount of attention, there has been little beyond individual studies to assess its suitability or success for citizen science; similarly, while frameworks exist for assessing citizen science performance, they tend to lack any appreciation of the effects that game elements might have had. We therefore review the literature to determine what the trends are regarding the performance of particular game elements or characteristics in citizen science, and survey existing projects to assess how popular different game features are. Investigating this phenomenon further, we then present the results of a series of interviews carried out with the EyeWire citizen science project team to understand more about how gamification elements are introduced, monitored, and assessed in a live project. Our findings suggest that projects use a range of game elements with points and leaderboards the most popular, particularly in projects that describe themselves as "games." Currently, gamification appears to be effective in citizen science for maintaining engagement with existing communities, but shows limited impact for attracting new players.

CCS Concepts: • **Human-centered computing** → *Computer supported cooperative work*;

Additional Key Words and Phrases: Citizen science, gamification, social computing, engagement, motivation

ACM Reference format:
Elena Simperl, Neal Reeves, Chris Phethean, Todd Lynes, and Ramine Tinati. 2018. Is Virtual Citizen Science A Game? *ACM Trans. Soc. Comput.* 1, 2, Article 6 (June 2018), 39 pages.
https://doi.org/10.1145/3209960

1 INTRODUCTION

Online, or Virtual, Citizen Science (VCS) uses Web-based techniques to allow members of the public to participate as volunteers in a scientific research project, without possessing expert knowledge about the subject at hand. This may fall into almost any domain, with notable examples in astronomy, zoology, and healthcare where using the Web to facilitate citizen science has proved to

This research was carried out thanks to the Stars4All EU Horizon 2020 Framework Programme grant, agreement no. 688135; the UK Engineering and Physical Sciences Research Council (EPSRC) SOCIAM: the Theory and Practice of Social Machines grant, agreement no. EP/J017728/1; and the Digital Economy programme, led by the Engineering and Physical Sciences Research Council on behalf of UK Research and Innovation, agreement no. EP/G036926/1.

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ACM 2469-7818/2018/06-ART6 $15.00
https://doi.org/10.1145/3209960

be a successful application of crowdsourcing for problems which are computationally unfeasible or inaccurate, such as classifying images of galaxies or identifying animals. However, while there are solid examples of success, a continuing challenge in VCS centers on how to increase both the number of participants, and their ongoing engagement with the project. This may be in order to create greater contributions with regard to the amount of work completed, the length of time the player participates, or the quality of the data that they produce by doing so, but also simply just to allow a wide range of players to contribute effectively, and in turn making the output of the project a useful contribution to science.

Drawing on many methods and theories from Human-Computer Interaction (HCI) and Computer-Supported Co-operative Work (CSCW), a key area of citizen science research looks at how a system can be designed in order to influence user behaviour and encourage people to interact with, and contribute to, the project. One such approach is to include game elements within the project, in order to increase the attractiveness of the work, motivate continued performance, and therefore improve user retention.

The inclusion of elements from game design within non-game environments, commonly described with the term "gamification," has increased rapidly over recent years. This has occurred across a wide range of applications and is a valuable tool for researchers and scientists wishing to undertake studies using large audiences (Deterding et al. 2011a). Gamification has been studied previously in the context of VCS to determine how it can be used to increase participation (see, e.g., Tinati et al. (2016)); however, while it has received a lot of attention, little has yet been done to look specifically at how the inclusion of specific elements relates to the subsequent success of the project.

There is also an ongoing debate about whether the use of extrinsic rewards, such as those offered through completing a game, are a good motivational strategy. In a review of 128 experiments, Deci et al. (1999) concludes that "tangible" rewards (such as money) tend to have a negative effect on people's intrinsic motivation to work or contribute. According to Self-Determination Theory (SDT), humans seek out activities that satisfy motivational needs, one of which is autonomy, and the attachment of extrinsic motivators such as rewards can reduce this experience (Deci et al. 1999; Deterding 2011). However as games are played voluntarily, there is an argument that this in itself provides the experience of autonomy, and thus the accumulation of points or badges for example through choosing to play the game itself is intrinsically motivating (Deterding 2011). While there are certain conditions that can ensure that the effect of extrinsic rewards is negated, Deci et al. (1999) summarise their review by stating that focusing only on extrinsic rewards can risk a reduction in intrinsic motivation. In crowdsourcing, studies have shown that there is a wide range of motivators, both intrinsic and extrinsic, behind why people choose to participate (Morschheuser et al. 2017). In terms of citizen science games, McGonigal argues that the addition of "meaning," or the sense that by playing the volunteer is belonging to and contributing something significant, is an intrinsic motivator that can make them feel a part of something much bigger than themselves (McGonigal 2011, pp. 49–51). This desire to participate in scientific research has also been shown to be one of the biggest draws to contributing to gamified projects, while the intellectual challenge as presented by the game then helped to maintain involvement (Curtis 2015), suggesting that this combination does not necessarily show the negative effects forecast by Deci, Koestner, and Ryan in Deci et al. (1999). Previous VCS research, examining games such as FoldIt (Curtis 2015), EyeWire (Iacovides et al. 2013), and EteRNA (Bohannon 2014) tends to consider gamification to have a positive effect, but lacks in-depth analysis behind what the project teams mean by "success" or how the use of game elements helps to produce this. Further insights about the positive—or negative—impacts of gamification are required if there is to be an end to the gap in knowledge about how best to use these techniques.

The motivations of this article are as follows. Firstly, there is a need to improve understanding around the success of game elements in citizen science projects and greater insights into how gamification can be and is used (Deterding et al. 2011a). Previous research has been carried out regarding the level of success in citizen science in general (see, e.g., the framework of success for assessing projects in Graham et al. (2015)). However, existing studies—to the best of our knowledge—have not looked broadly at how gamification might contribute to this success, such as which elements are effective in increasing user engagement, whether or not a gamified approach is typically successful, or how designers decide which game features to include. Furthermore, VCS is a diverse field and there are currently few overviews that detail how game elements and characteristics are currently being used in this space—and equally crucially, why these design decisions are being made, particularly in cases where they diverge from literature recommendations.

To this end, we review findings from the VCS literature to assess empirical findings on the reported performance of gamification across a range of VCS domains. We discuss the ways in which elements are implemented and review whether they have a positive, negative, or mixed effect on volunteer engagement, performance, and motivation. Based on these findings, we then carry out a survey of 31 VCS projects including games and non-games, to understand the extent to which findings and recommendations from the literature are put into practice and also to explore the distinction, if any, between what it means for a project to call itself a "game." To understand the reasoning behind these design decisions, we then supplement this literature and project survey with findings from interviews with all members of the design team behind the gamified VCS project EyeWire.[1] We find that certain game elements (points and leaderboards) are commonly used, with others such as badges, rewards, and statuses building on these, and these elements are used more on projects that describe themselves as "games." Projects that do not describe themselves in this way appear to focus more on learning and education, suggesting a different approach to engaging volunteers. Nonetheless, these elements often diverge from those recommended in the literature, with extrinsic and competitive elements more commonly used than the cooperative and intrinsic, progression-based game play supported by the literature. Our interviews with the EyeWire team give insights into the reasoning behind such design decisions, showing that the project team is predominantly influenced by player feedback and the need to ensure long-term player engagement. Development restrictions play a crucial role in preventing the team from expanding the project and changes are typically made without much influence from what other citizen science games are reporting to have been successful. Throughout our findings we observe tensions between what it means to be a "game" and the needs of a VCS project—particularly in terms of the expectations of players.

The remainder of this article is structured as follows. Firstly, we present a background introduction to VCS and gamification, and how they have been used together. We then review the existing literature on the effects of gamification in VCS, examining studies to see how effective the use of game elements has been in real-world projects. The first contribution of this article summarises findings from the literature identifying the impact of different game features on player engagement and output quality. Secondly, our survey of VCS projects explores the extent to which these recommendations are employed in projects and the popularity of different features both in contexts which use the "game" descriptor and those which do not. Finally, our third contribution draws on the interview-based study with the EyeWire team to understand the decision-making processes required for the successful design and implementation of VCS games. We envisage that these insights can be used by citizen science project designers to consider the potential impact of different game elements, along with how to track these effects so that meaningful insights can be gained from them, and by VCS scholars interested in tracking the overall success of gamification in this domain.

[1] http://eyewire.org/explore.

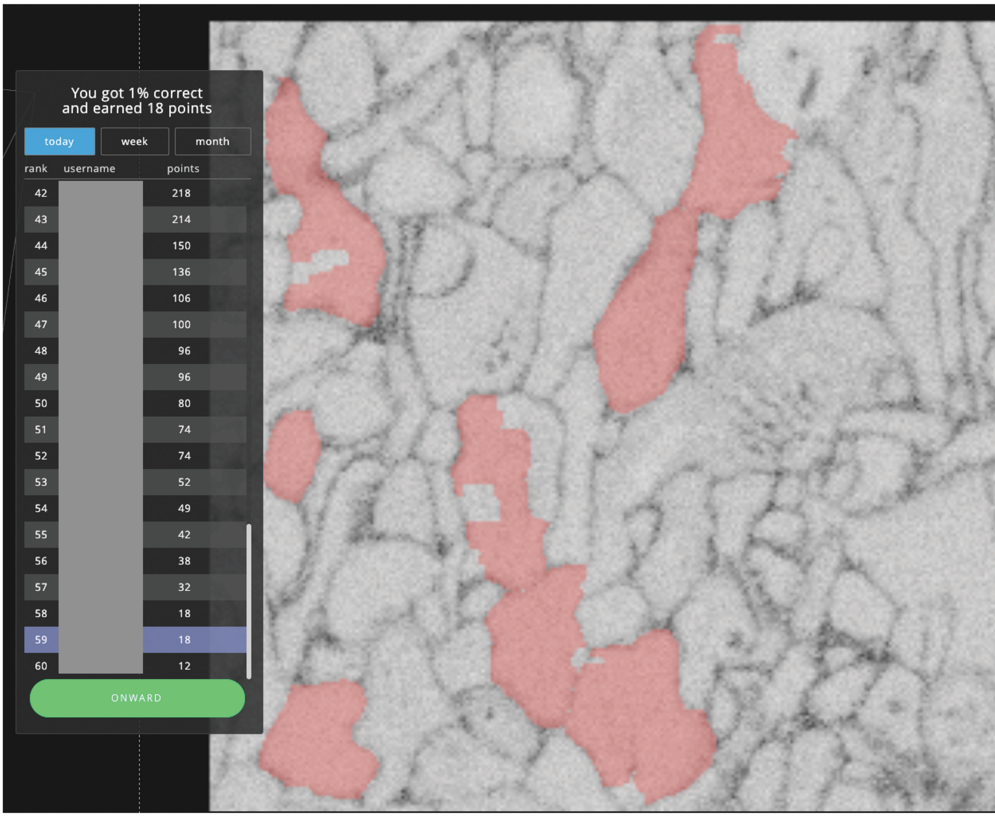

Fig. 1. The EyeWire game interface, showing accuracy, points acquired, and the leaderboard. Usernames have been obscured for privacy. http://eyewire.org

2 BACKGROUND AND RELATED WORK

2.1 Virtual Citizen Science

VCS allows scientists to process large amounts of data using human computation, to complete tasks that would otherwise take unfeasible lengths of time or require potential sacrifices to accuracy to be carried out using machines. It draws upon theories from HCI and CSCW, and typically makes use of a digital platform to allow professional scientists to crowdsource contributions to their research from large numbers of people (Howe 2006). The use of the public for collecting and analysing data is becoming an important part of science (Tinati et al. 2015) with projects showing notable levels of success—including, for example, the galaxy-classifying web application Galaxy Zoo (Lintott et al. 2008).

A VCS project can be based in almost any domain; current projects can be found in a hugely diverse range of topics. While citizen science projects can include manual, offline work such as the recording of wildlife in participants' gardens[2], VCS projects are typically conducted online (such as in EyeWire; Figure 1), making use of both the prevalence of the Web to reach huge numbers of people and of large computer clusters that can subsequently store, manage, and process the

[2]See, for example, the iNaturalist project, where participants track and record details of their wildlife observations; https://www.inaturalist.org/.

resulting deluge of data. The results are aggregated to provide a level of assurance that the data is accurate, with the aim being to allow the scientists to access a result at a much faster speed than if they had to process all the data themselves. For example, the crowd approach was shown to be more scalable and economical than an automated solution for analysing images related to particle-tracking problems (Chen et al. 2016).

Using crowdsourcing for science is not anything inherently new; services such as SETI@home (Anderson et al. 2002) have long offered participants the chances to allow processing time on their own computers to assist with scientific research. In recent years, however, increased focus has been placed on using the volunteers themselves as the means of computation—either in terms of data analysis or data collection and curation. The smartphone age has given rise to the opportunity for "participatory sensing," allowing volunteers to record all types of phenomena using their mobile device (Restuccia et al. 2016). Relying on the ability of the human brain to complete tasks such as the analysis of images is quicker than even the most powerful of supercomputers (Kawrykow et al. 2012). Similar to SETI@home, VCS projects allow people to contribute without being a professional scientist. Comparable to the process followed in an assembly line, a complex scientific task is split into a number of simpler "microtasks," each of which is basic enough to be solved by a non-expert. The tasks may include cataloguing or classifying items, mapping structures within images, or transcribing text, following a set of guidelines. These guidelines mean that anyone can participate without the typical level of expertise required in the subject area (Tinati et al. 2015). The EyeWire project, for example, breaks down a complex neuroscience problem of mapping the connectome in the brain by asking players to map the branches of single neurons in a three-dimensional puzzle game.

2.2 Gamification

Gamification is a term "*mired in diverse meanings and contradictory uses*" (Seaborn and Fels 2015). However, a frequently used definition stems from Deterding et al.: "*[u]sing game design elements in non-gaming contexts*" (Deterding et al. 2011b). Other definitions refer to the need for gamification to invoke similar psychological experiences that a player would feel when playing a "traditional" game, or "*a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation*" (Huotari and Hamari 2012). Furthermore, Hamari et al. (2014) conceptualises gamification as having three parts in order to connect the existing literature on the topic: (1) **motivational affordances** refer to what specific features have been implemented to make the system a game and increase motivation; (2) **psychological outcomes** are the resulting variables that have been measured relating to motivation, attitude, and enjoyment, whereas (3) **behavioural outcomes** are those most typically reported in studies and relate to the resulting actions of the player (Hamari et al. 2014).

2.2.1 Game Elements. As a first step towards understanding gamficiation better, Deterding et al. created a taxonomy of elements that are used in projects to frame a task as a game. These game design elements may fall into the following levels of abstraction: (1) game interface design patterns, (2) game design patterns and mechanics, (3) game design principles and heuristics, (4) game models, and (5) game design methods (Deterding et al. 2011a). Building on this, a number of specific game elements are then outlined in Seaborn and Fels (2015): points, badges, leaderboards, progression, status, levels, rewards, and roles. Therefore, the popular definition of Deterding above relates to the use of these features in non-gaming contexts. For this article, we focus on their use more specifically in VCS projects and we investigate the extent to which they have been successful.

Points are referred to as a numerical metric of progress, representing the user's current score. **Badges** or trophies are visual icons awarded for completing some form of achievement, whether

Table 1. Game Elements Listed by Seaborn and Fels (2015), Associated with Dynamics and Motives from Blohm and Leimeister (2013) and the Self-Determination Theory Concepts Outlines in Aparicio et al. (2012) According to Common Aims and Impacts on Participants

Element (mechanic)	Element (dynamic)	Motives	SDT concept
Badges	Collection	Achievement	Competence
Points	Collection	Achievement	Competence
Progression	Acquisition of status	Social recognition	Competence/Autonomy
Status	Acquisition of status	Social recognition	Competence
Levels	Acquisition of status	Social recognition	Competence
Leaderboards	Competition	Social recognition	Competence
Rewards	Collection	Achievement	Competence
Roles	Collaboration	Social exchange	Competence/Relatedness

this is from completing a specific task or accumulating a certain number of points. Their use has been studied in many situations to increase engagement with Web-based sites (e.g., Easley and Ghosh (2016)). In VCS projects, badges may be assigned for performance-contingent reasons as in EyeWire, where high accuracy and point scores are rewarded, or simply for exceeding a set threshold of contributions, as in the Notes from Nature project (Reeves et al. 2017). Players are ranked by their score on **leaderboards**, and each individual's **progression** through the game is determined by the various milestones or key tasks they have achieved, such as completing certain levels or alternatively "levelling up." Depending on their current progression, a player may receive a particular title or "**status**," which may increase as the player traverses increasingly challenging **levels** or stages in the game. Players are motivated to continue in the game in the hope of receiving **rewards**, which may be real-world items or items to use within the game itself. Finally, a player may take on one or more **roles** within the game, depending on the type of character they play as (Seaborn and Fels 2015). Alternatively, players may be assigned roles based on previous behaviour and achievements, allowing access to new tools or opportunities for contribution (Reeves et al. 2017). Taking these game elements as a starting point, we examine their features according to a number of theoretical frameworks on gamification in Table 1.

In their review of gamified e-participation tools, Thiel presents an overview of different game elements found throughout their literature search (Thiel 2016; Thiel et al. 2016), made up of achievement (e.g., badges), points, status (or levels), spaces for expression and creativity, feedback (such as notifications), personalisation (e.g., through profiles), challenge (missions, quests, etc.), competition, and time constraints. Thiel's overview shows similarities to the list of elements presented by Seaborn and Fels (Seaborn and Fels 2015) which contain many of these features.

There are further characteristics of gamified projects that can be found in the literature but which do not necessarily constitute "game elements"—they merely relate to design decisions of the project around the game, without actually impacting the core mechanics of the game itself. **Narrative** is a key element in many games; it is the series or sequence of events that help to guide the player through the game's story (Rudrum 2005). The ability to **skip** is another game feature that allows players to move on to another task without completing the one they are currently assigned to. Skipping is assumed to help to keep players motivated if they encounter a particularly challenging or confusing stage or level in the game. The intended usage of the skip functionality suggests that it provides players with a sense of autonomy as described in SDT (Deterding 2011). Additionally, numerous games will offer a **tutorial** or practise process that aims to get players started with the tasks involved and is necessary in more complicated games—for example, by completing a specially designed set of puzzles or tasks before proceeding to the true scientific task

(Curtis 2015). Those without a tutorial can be labelled as self-explanatory, indicating that the task is simple enough that players can generally begin playing without any formal introduction to the task. Many games also offer the opportunity for **learning** and this is common in VCS projects as the games are based around scientific research, and the process of educating citizens is motivating for both the scientists and the volunteers themselves (Rotman et al. 2012).

2.2.2 Gamification for Engagement. This section details the use of gamification in a range of contexts—for a discussion of gamification in VCS, please see the following section. As discussed in Section 1, there is a debate about whether offering extrinsic rewards is a good strategy for increasing motivation. Deci et al. warn that in many situations these could negatively affect people's intrinsic motivations (Deci et al. 1999), whereas others argue that a game itself is intrinsically motivating (Deterding 2011). Motivated by this debate, Hamari et al. analysed 24 empirical studies on gamification and found that, generally, the technique does work, albeit with some caveats that were often to do with positive effects only being found for a particular type of use or user (Hamari et al. 2014). In addition, a review of studies about gamification's use in crowdsourcing found that its use typically leads to an increase in engagement, output quality, or other related positive effects (Morschheuser et al. 2016), while an extended review supported these findings to show that it increases participation and quality of crowdsourced work (Morschheuser et al. 2017). There is an additional consideration that context may well be key, and that certain systems that rely primarily on rational behaviour are not suited to being gamified (Hamari 2013; Hamari et al. 2014). Finally, the results in Hamari et al. (2014) show that people interact with games and gamified systems in different ways, and therefore they are likely also to have different experiences with a system that incorporates game elements.

Gamification appears to be popular for younger participants in crowdsourcing, but less so for other age groups (Baruch et al. 2016). Instead, some participants are drawn to these systems through **altruism**, and their engagement is maintained through egoism and collectivism, rather than competing to move up a leaderboard (Baruch et al. 2016). Other projects may focus on **sociability**, or as described by George Simmel, the "*sheer pleasure of the company of others*" (Ducheneaut et al. 2007). This interaction may be afforded through features such as forums and chat boxes which facilitate discussion among participants. Similarly, collaboration is a way of framing the game that requires people to work together to complete a task. These are alternative ways that a game may be framed rather than the standard **competition**-based mechanisms.

2.2.3 Gamification in Virtual Citizen Science. Gamification has emerged onto the VCS scene partly due to cheaper technology, but also thanks to personal data tracking and the familiarity people now have with "games" as a medium (Deterding 2012; Seaborn and Fels 2015). There is already a growing body of literature discussing the merits and advantages of gamification in individual citizen science projects, with findings suggesting increased success in attracting Millennials, and end results such as increased community awareness (Bowser et al. 2013). However, despite the generally well-received nature of gamification, studies have suggested that certain aspects of it may turn away certain participants—for example, in the Old Weather project there appears to be a disparity between those participants who are driven to compete thanks to the use of certain mechanisms, and those more casual users who ignore them or, in some cases, decided to completely withdraw from the project (Eveleigh et al. 2013). This finding is supported by research into gamification in crowdsourcing which suggests that it could detract from the experience for certain demographics (Baruch et al. 2016). Where the literature is lacking is in broad assessments of the insights from existing projects that collectively could shed light on whether gamification is typically an effective way to increase volunteer performance with VCS. Metrics have been elicited, split around two main elements (contribution to science and public engagement), for

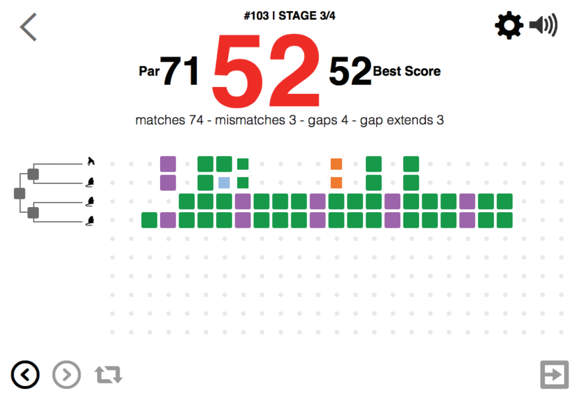

Fig. 2. The Phylo game interface: http://phylo.cs.mcgill.ca.

measuring the success of online citizen science projects in general, but these have yet to be used for measuring the effects of gamification (Graham et al. 2015). There is a distinction within the literature between gamification and gamified projects—that is, those which take scientific tasks and apply game elements—and Games With a Purpose or serious games—that is, highly game-like activities such as puzzles which are applied in scientific research in projects such as Phylo (figure 2).

3 LITERATURE REVIEW

This section details the results of a literature review conducted across four databases. We begin by detailing the methodology used to find and sample publications. In terms of results, our findings discuss empirical evidence detailing the impact of gamification on volunteer motivation and distinctions with less gamified contexts, impacts on output data, and the impact of specific features.

We group findings from the relevant research papers below, categorising the outcomes under a number of themes relating to how games can be employed within VCS. These themes were determined through discussion between the authors, based on commonalities in the abstracts, findings, and keywords of the research papers. We summarise the findings in Table 7, using the conceptualisation of gamification outcomes presented in Hamari et al. (2014).

3.1 Methodology

We reviewed the existing literature for papers detailing the experiences of utilising game elements within VCS, focusing on those which offer evidence of the impact that this approach has made. While literature surveys have previously been carried out on empirical studies into gamification in general (see Hamari et al. (2014)), showing that it does tend to produce positive effects, there has yet to be any specific look at what the effects have been in the context of VCS, which is important as effects appear to be context-sensitive.

We selected four databases: the ACM Digital Library, JSTOR, SCOPUS, and the Web of Science service. Two search procedures were conducted—one search for "citizen science" and "gamifcation" and a second, separate search for "games with a purpose." Each search was carried out to cover all publications up to and including those published within 2017. More specific information on the search terms used and the number of results can be seen in Table 2. A total of 517 results were collected across the four databases, of which 344 results were unique.

Table 2. Databases and Search Terms Used and Results Generated

Repository	Search terms	Results
ACM Digital Library	recordAbstract:(+"citizen science," "gamification")	13
	recordAbstract:(+"games with a purpose")	62
JSTOR	("citizen science" AND ("gamification")	1
	("games with a purpose")	12
SCOPUS	(TITLE-ABS-KEY("citizen science")) AND (TITLE-ABS-KEY("gamification"))	35
	TITLE-ABS-KEY("games with a purpose")	302
Web of Science	TOPIC:("citizen science") AND TOPIC:("gamification")	17
	TOPIC("games with a purpose")	87
Total	N/A	517

Table 3. Number of Papers by Category

Count	Description
189	Duplicated or highly similar publications
68	Not empirical studies
47	Not peer reviewed academic papers
3	Not related to gamification
82	Not related to citizen science
24	Results or description of systems
44	Irrelevant topics

As it was our intention to find specific evidence for the impact of gamification features, we introduced a set of selection criteria aimed at filtering irrelevant and theoretical sources. The results of each search were analysed by two separate researchers and overseen by a third researcher who identified and resolved any disagreements between the results. Papers were initially assessed for relevance based on title, keywords, and abstracts, and duplicated results, as well as those with no relevance to gamification or citizen science were removed from the sample. The remaining publications were analysed at the full text level to ensure the presence of empirical evidence and relevance to the topic of the effectiveness and impact of gamification features in citizen science. The decision was made at this stage to remove those publications describing the results of systems, due to the lack of specific evidence for the effectiveness of particular features and methods of implementation. Table 3 details the number of papers removed, as well as the reason for these removals. A final total of 54 papers was selected for review, which can be seen in Table 7.

3.2 Competition Versus Collaboration

In the Old Weather project, surveys and interviews were carried out with participants to discuss the appeal of the gamified approach. The results revealed a conflict between those who found the mechanisms motivating, and those who were turned off by the same features (Eveleigh et al. 2013). Point scores were suggested to be demotivating to medium and lower scoring participants, and the title, while attempting to achieve a higher title by proceeding through the collection-based leaderboard system was stressful, leading participants to switch to less competitive collections. Moreover, the existence of points and reward systems such as badges and titles encouraged some participants to leave the project, as they found such elements to be trivial—a characteristic that was at odds with the serious nature of the research involved. Evaluating the Happy Match project, Crowston and Prestopnik (2013) found that there was a slight indication that participants would be motivated by additional competitive elements, again suggesting that this is a feature that is not universally welcomed or rejected. Other studies have shown that player performance may be increased by showing the progress of a "virtual peer" whose progress offers a means of comparison for the participant (Laut et al. 2016). It has been proposed that more granular and personal scores and targets are required to ensure participants feel valued throughout, with an emphasis on quality rather than quantity (Eveleigh et al. 2013). Additionally, team-based challenges or prizes could help to ensure that some volunteers' interest is maintained, negating the problem of some users feeling they were already too far down the rankings (Eveleigh et al. 2013).

Alternatively, Curtis (2015) found that "friendly competition" was not a driver for players to participate in the Foldit game; contributing to science and an intellectual challenge were instead much bigger motivations. Curtis (2015) also suggests that game elements offering interaction and collaboration may be more motivational than competitive elements, again demonstrating the different attitudes towards these types of games. Baruch et al. (2016) states that while gamification is popular among younger participants of the crowdsourcing platform Tomnod, it detracts from the experience of others, and cooperation is generally more desirable than competition for all users. This may be related to different types of contributors: Eveleigh et al. (2014) discuss the difference between high contributors who are deeply engaged with the competitive elements of Old Weather, and low contributors who tend to only try out projects for short periods. Eveleigh et al. (2014) emphasise the need to encourage "long-term dabbling," suggesting that breaking tasks into smaller-scale problems can help appeal to the majority of participants' short attention spans.

3.3 Maintaining Engagement

Opportunities to build social relationships with fellow players through game activity have been shown to encourage long-term, lasting participation. Curtis (2015) details the formation of friendships between FoldIt players and the impact that these friendships have on encouraging players to continue to play the game. Similarly, these team- and community-based relationships were also observed to be essential to overcome difficult puzzles and to learn to contribute to a relatively difficult scientific problem (Curtis 2015). In particular, team formation was noted to enable newer players to overcome the demanding and lengthy tutorial process, thereby enabling and encouraging continued participation by preventing new players from becoming frustrated (Curtis 2015). Similar findings were reported by Iacovides et al. (2013) from exploratory interviews with FoldIt and EyeWire players. Players reported that the chance to join and contribute as teams was essential for their continued participation in FoldIt (Iacovides et al. 2013). While EyeWire does not allow explicit team formation, a survey of player motivations for chat participation found that participants nevertheless found ways to collaborate and help one another—particularly when helping newer players learn difficult tasks, as in FoldIt (Tinati et al. 2015).

The impact of extrinsic reward mechanisms was more mixed. In interviews with Iacovides et al. (2013), players described the urge to extend play sessions to maximise progress, as indicated by point and leaderboard mechanics. However, this was suggested to result from a desire to be part of assisting scientists in completing research that would otherwise be impractical—rather than any interest in point or leaderboard rankings. This is echoed by findings from the Quantum Moves platform, where the presence of leaderboards was demonstrated to have no statistically significant impact on players' likelihood to return to the game (Pedersen et al. 2017). Conversely, Prestopnik et al. (2014) suggest that points-based gaming is effective in encouraging long-term play. Prestopnik et al. (2014) noted that points-based games were associated with higher volunteer retention rates than progression and narrative-based gaming. A follow-up study by the authors suggested that this results from players exhausting progression opportunities (Prestopnik et al. 2017). While players can eventually exhaust progression and narrative mechanisms, the opportunity to earn points persists as long as players contribute to games. The opportunity to build scripts to outperform fellow players and maximise point gains has also been stated by some FoldIt players to be key to their continued interest in the game (Ponti et al. 2015).

Once a player has been attracted to the game, there are differences in the way that the game itself is implemented that can affect participation. Story-based games have been shown to be preferable compared to points-based games (Prestopnik and Tang 2015). Participants were motivated to continue playing as activities were "story-focused," suggesting that these types of games may be particularly effective for VCS projects, especially if the player is not interested in the scientific outputs (Prestopnik and Tang 2015). The authors suggest that this type of game could help to balance the contributions that are typically skewed towards a few members of the community—a community that is typically made up of people interested in the science rather than just playing a game (Prestopnik and Tang 2015).

Social Factors and Cooperation. Iacovides et al. (2013) found that the provision of discussion features such as chat and forum platforms was important for developing a sense of community. These opportunities for team interaction and for team-play were important motivators for continued player engagement. Further, Eveleigh et al. (2013) suggest that the implementation of team-based activities and rewards could be used to reduce the potentially demotivating impact that competition has on underperforming individuals. This is echoed by Baruch et al. (2016) who note that users of the crowdsourcing platform Tomnod responded more favourably to cooperative elements than to competitive elements.

Competition. The inclusion of competitive elements has been found to lead to increased levels of contribution, but lower levels of effort in tagging tasks—while players generate more tags, the time taken for each tag and the quality of tags is lower in competitive games (Siu et al. 2014). The impact of competition is also highly dependent on the performance of other players. While players will display increased participation in the face of competition, participation will decrease if fellow players are deemed to contribute too much or too little. Experimenting with a virtual peer, Laut et al. (2016) found that players adjust their behaviour to match peers, reducing contributions when peers are less active and increasing contributions as peer's activity increases. This effect is only seen, however, where such levels are seen as achievable. Opportunities for competition can be particularly demotivating to casual participants and newcomers, who find themselves outperformed by more active and longer-term players, leading less active players to leave projects (Eveleigh et al. 2013).

Feedback. Evidence of progress was identified by participants of FoldIt and EyeWire as a rewarding element of games that positively reinforces player participation, leading to increased activity (Iacovides et al. 2013). Feedback features have also been found to assist players in adapting the way they contribute. Fylo contributors found that game elements provided additional information which was useful for informing their behaviours (Forde et al. 2016). Nevertheless, this had no significant impact on the players' intrinsic motivations, nor their competency, suggesting the impact of such features is minimal.

3.4 Participant Motivation

The appeal of participating in science was strongly emphasised in the literature, particularly by Iacovides et al. (2013). In the EyeWire platform, Tinati et al. (2016) surveyed participant motivations in the citizen science game EyeWire, finding that the most significant factor influencing player participation was the desire to contribute to scientific research. This is similar to other VCS research that has shown that a desire to contribute to scientific research is a strong motivation for participation (Raddick et al. 2013). Jennett et al. (2016) note that the factors governing initial attraction to citizen science almost exclusively pertain to scientific research—interests in science, curiosity about research, and a desire to contribute to research. Nevertheless, continued interest in projects is a significant factor influencing long-term player engagement (Jennett et al. 2016) and our findings suggest that it is in this area that games have a significant influence.

Perspectives on the motivational value of game elements were mixed. Forde et al. (2016) suggest that the addition of gamified elements has no significant impact on intrinsic motivations. Similarly, from Iacovides et al. (2013) in interviews with participants in EyeWire and FoldIt, it was found that game elements did not necessarily attract players to the project—their intrinsic interest in the science was enough—but such elements had some motivational value in providing recognition that participants were contributing. Similarly, Curtis (2015) found that FoldIt players were predominantly motivated by altruistic desires to contribute to science, rather than extrinsic mechanisms such as points and competitive elements.

Reward-based game elements such as points have been noted to impact negatively on those participants who show strong intrinsic motivations (Prestopnik and Tang 2015). Even among those players who are more extrinsically motivated, Siu and Riedl (2016) describe that gaming alone was insufficient to overcome the boredom associated with repetitive human computation tasks, particularly where players derived fun from collecting extrinsic factors such as game unlockables. On the other hand, Bowser et al. (2013) suggest that reward-based game elements such as badges are associated with player interest and enjoyment and that as a result, these features do in fact increase the motivation to participate.

Further, in spite of the importance of altruistic and intrinsic interests in science suggested above, Greenhill et al. (2016) describe highly gamified features with no scientific purpose. The Zooniverse's *Voorwerp Pong* drew significant interest from project participants, despite lacking any scientific purpose. Greenhill et al. (2016) suggest that both intrinsic factors such as a desire to have fun and extrinsic factors such as points, leaderboard rankings, and rewards are key to driving participation in gamified citizen science.

3.5 Output Data Quality

In some cases, project teams have suggested that introducing gamification elements has been detrimental to the quality or accuracy of the data produced.[3] A comparison of GWAPs with microtask crowdsourcing platforms conducted by Thaler et al. (2012) found that the proportion of correct responses submitted within the GWAP was 15% lower than within the crowdsourcing platform (74.87% compared with 89.75%). However, a similar study carried out by Sabou et al. (2013) found the performance of crowdsourcing platform participants to be highly interface-reliant, with game players matching or even exceeding the performance of microtask crowdsourcing. Within human computation, Chung et al. (2017) have also observed differences in player performance based on the visual load of tasks. By providing participants with more information and more on-screen subjects for analysis, players were able to better formulate gameplay strategies, with the mean performance of players increasing by 80%.

Aiming to address some of these concerns, Prestopnik et al. (2014) compared the quality of data produced by one gamified project with one that was presented as a game that required users to complete a task in order to progress (note the differentiation between a project that includes "*gamified*" elements, and one which presents itself as a game, which we return to later). While the game-based project did introduce cheating as a strategy among players, overall (excluding the cheating behaviour) there was no significant difference in performance (Prestopnik et al. 2014). Similar findings have been made in other domains, around adding competitive elements in crowdsourcing

[3]For example, see http://www.cancerresearchuk.org/support-us/citizen-science/the-projects #citizenscience1.

to improve volunteer output without harming the quality of the data they produce (Rokicki et al. 2016). Taking a somewhat different approach, the effects of collaborative and competitive game elements have been studied, based on how they affect player engagement and accuracy in games with a purpose (GWAPs). Results suggested that as well as improving engagement, competition produced results that were as accurate as collaboration (Siu et al. 2014). Of note was the finding that when combined—when a player is presented with both competitive and collaborative scoring options—performance levels decreased (Siu et al. 2014). Similarly, Goh et al. (2010) demonstrate that competitive models outperform collaborative models in image matching tasks, due to players' rewards and progress being more dependent on the quality of submissions. This is not the case for all activities, however. Framing image-matching tasks in combined collaborative, competitive game-based activities has been shown to increase the quality of labels generated by players (Huang and Fu 2012).

Nevertheless, concerns remain about the impact of competition on data quality. A number of studies surveyed associated competitive elements with reductions in the time spent by volunteers on each contribution, raising the possibility that participants could rush, introducing errors to data (Mekler et al. 2013; Siu et al. 2014). Furthermore, players showed an unwillingness to provide some forms of data, regardless of the rewards offered by games, leading to incomplete data submissions (Kapenekakis and Chorianopoulos 2017). While game features generally had little effect when attempting to increase the accuracy and quality of submissions, studies suggest that players are influenced by the way in which tasks are framed. Presenting tasks in a manner which emphasises their scientific value and players' altruistic motivations encourages players to spend greater time and effort on each submission—leading to an increase in the quality of submissions without reducing engagement (Mekler et al. 2013).

4 CITIZEN SCIENCE PROJECT SURVEY

4.1 Methodology

In order to obtain a more complete picture about the uptake and use of these elements, we surveyed and observed a number of projects, and quantified how frequently each type of game feature was used. To focus only on "virtual citizen science projects," we used the typology presented by Wiggins and Crowston (Wiggins and Crowston 2011) that suggests such a project should require no physical elements whatsoever (e.g., paper-based data collection). Therefore, we targeted only those projects in which all stages were carried out via digital means.

We subsequently consulted the human-curated list of citizen science projects on Wikipedia, and the same list for human-based computation games, which we then manually filtered to obtain a sub-list of active VCS projects. The lists were retrieved from Wikipedia in November 2015. Projects were removed if they involved offline activity (97), the project website was closed or had failed at the time of study (4), the website for the project had ceased (5), there was no English language version available (2), or in the case of the human computation projects there was no proof that it was a citizen science project (1). In addition, there were a number of projects that appeared in both lists, so duplicates were removed (4).

Across both lists we found a high number of incidences of projects drawn from the Zooniverse platform. These projects were generally very similar, with few (if any) gamified elements and represented the majority of the sampled lists. In these cases, we made the decision that where there were numerous projects from the same platform, each of which typically used a similar set of features and shared many characteristics, we took a subset of these projects. Such restrictions were particularly necessary given the possibility that just the one, predominantly non-gamified platform would have a much more significant impact on findings. We obtained a final list of 31

Table 4. Game Elements and Characteristics Surveyed in Each Project

Game Elements	Game Characteristics
Points	Narrative
Badges	Altruistic framing
Leaderboards	Sociability
Progression	Tutorial
Status	Collaboration
Rewards	Competition
Roles	Learning
-	Option to skip

Table 5. Survey Results for Projects Describing Themselves as Games and Projects not Described as Games

Game Element	"Game" Projects (N=14)	Non-Game Projects (N=17)
Points	13	4
Badges	5	4
Leaderboards	11	6
Progression	7	2
Status	5	1
Rewards	4	4
Roles	1	3
Narrative	5	1
Altruism	11	15
Sociality	6	9
Tutorial	7	12
Collaboration	4	8
Competition	12	5
Learning	3	13
Skip	6	6

VCS projects that we then assessed in order to establish the prevalence of different game elements. The final selection (see Appendix 8) is not intended to be an exhaustive list of all VCS projects (particularly because we filtered many similar Zooniverse projects); rather, we were interested in finding those projects with sustained activity (indicating sufficient popularity to avoid closing) that could be used to assess design decisions.

For each project, we assessed whether or not it included certain game elements or characteristics; specifically, points, badges, leaderboards, progression, status, rewards, roles, narrative, altruistic framing, sociability, tutorial, collaboration, competition, learning, skip (also depicted in Table 4).

4.2 Results

The previous section shows that the literature has a generally positive perspective on a number of game elements in certain projects. Our survey of projects revealed the extent to which various elements were employed by the 31 projects in our sample, with the results depicted in Table 5.

4.3 Comparison with Literature Findings

Overall, our results demonstrate that the game mechanics of citizen science games predominantly rely on providing extrinsic rewards for participation—rewards such as points and leaderboard rankings. As points are probably the most basic form of tracking a user's progress through the game, this is perhaps not surprising; badges, progression, status, rewards, and roles are all features that would in most instances need to build on the implementation of points in the first place. Nevertheless, although the findings of our literature review suggest that cooperative elements motivate greater participation than competitive elements, almost all of the 14 game projects leveraged competition as a game mechanic. Similarly, in spite of the effectiveness of narrative and progression-based gaming, these features were relatively uncommon and closely linked—progression was exclusively linked to proceeding through narrative arcs. Opportunities for social interaction were present in 50% of games, with few opportunities for group and team forming, contrary to the positive role these features can play in encouraging long-term participation.

While learning was not a motivation associated with gaming, we found a small number of games that offered players the chance to learn more about the underlying science associated with a game. In addition, perhaps contrary to the reliance on extrinsic motivations, the majority of projects framed tasks in terms of altruistic values and the importance of tasks for science. Tutorial systems were present in around half of the games surveyed, to assist players in learning how to contribute. These systems varied in complexity, length, and the effort demanded of players—FoldIt featured the longest tutorial process. It should be noted that while tutorials helped players "learn" to play their respective games, these tutorials were not learning features—none of the tutorials explained the underlying scientific research.

4.4 Distinguishing Games from Non-Game Projects

In order to extract information about how the projects were described, compared with what elements they used, we also carried out a similar frequency check on the projects by splitting them on whether or not they described themselves as a "game." We searched for each project using Google, along with the word "game" and for those projects which provided no result (e.g., they listed the project, but with the word "game" missing), we then looked at the project website for references to it being a game. 14 of the 31 projects were found to describe themselves in some way as a game. In Table 5 we see that for the game elements from Seaborn and Fels' (points, badges, leaderboards, progression, status, roles), those projects that describe themselves as "games" do, unsurprisingly, make use of the elements to a greater extent than those which do not. However, for many of the other game characteristics, it is the "non-games" that more regularly demonstrate their use—exceptions to this are narrative and competition, which are much more popular in "games." Interestingly, it is the projects that do not describe themselves as games which focus more on the learning and education aspects of the work and as such suggests that these projects may instead be hoping to engage with volunteers in a different way, reflecting the suggestions from the literature that projects may offer success through different forms of framing (e.g., Curtis (2015)). This echoes the tensions described by Prestopnik and Tang (2015) and Eveleigh et al. (2013), among others, in terms of the impact of framing "serious" citizen science tasks as games. While games frame their tasks through the awarding of extrinsic factors for participation, non-games instead support intrinsic motivations by reinforcing players' intrinsic interests through learning and feedback (Jennett et al. 2016). There are, however, different degrees of such framing and it should be noted, that not describing the project as a game does not mean that it will not include any game elements at all. We therefore recognise an interesting difference:

(1) "Games" are those projects that are openly described as being a game, and include the implementation of game elements and characteristics.
(2) "Gamified projects" do not describe themselves as games, but include some kind of game mechanic.
(3) "Non-gamified projects" rely only on altruistic motivations and do not seek to improve user engagement through the use of game elements.

5 INTERVIEW FINDINGS

Building on the outputs of the studies discussed so far, this article aims to provide in-depth qualitative data about the role of game elements in a VCS project, for which interviews were carried out with the EyeWire project team.

5.1 Methodology

Semi-structured interviews were run during February 2017 with members of the design team for the EyeWire project—a gamified citizen science approach to mapping the human brain (see Figure 1). Three interview sessions were carried out in February 2016 by a single researcher, covering six participants who represent the entirety of the full-time staff working for the EyeWire project at the time. The six members of the staff were as follows:

(1) Community and Project Manager—Responsible for overseeing the project, this participant was interviewed alone during interview session one.
(2) Designer—Responsible for designing artistic and interface elements, this participant was interviewed alongside the developer during interview session two.
(3) Developer—Responsible for implementing new design elements and resolving system bugs, this participant was interviewed during session two.
(4) Game Master—Responsible for interacting with the community, planning and running community-engagement activities, and elicting feedback from the community. Interviewed during session three.
(5) Game Master—Interviewed during session three.
(6) Game Master—Interviewed during session three.

The purpose of the interviews was to understand the thought processes and design decisions taken by the citizen science designers relating to gamification elements, in order to provide further details about why these elements were introduced, how they are assessed by the project team (in terms of their performance relevant to the aim of the project), and whether or not it is felt that they are ultimately successful. We followed a semi-structured schedule in order to ensure that a key set of questions were asked and answered,[4] but wanted to allow the participants to deviate where necessary so that we could gain insights into the entire process of design and the reasons behind the introduction and use of gamification. We used thematic coding to analyse the interview transcripts (Pope et al. 2000), eliciting the concepts and themes discussed by each participant that help shed light on the perceived success of the game elements.

Interviews were transcribed by a single researcher, before being checked and corrected by a second researcher. These transcripts were initially coded by a single coder using NVivo, with a qualitative codebook used to allow flexibility as new themes were discovered within the interview transcripts. The process used was iterative: An initial set of codes was devised in anticipation of opinions and thoughts about the use of game elements and their effect on the citizen science

[4] A full list of these questions can be seen in appendix B.

project as a whole. A second thematic coding analysis was used based on this initial set of codes to extract the underlying themes from the participants' responses. The transcripts were then coded independently by a second researcher. Differences between the two coding schemas were analysed by a third researcher, responsible for resolving these differences. The remaining findings within this section are grouped according to the emergent themes identified during the thematic analysis process. A summary of the interview findings and the relevant respondents grouped by these themes can be found in Table 6.

5.2 Decision Making

Given the limited time and development resources available for the project, a common theme mentioned throughout the interview process was the need to carefully consider which features and changes should be made to the EyeWire project. In spite of the scientific needs of the project, the team predominantly described player-driven changes to gameplay and game features, rather than to the underlying scientific infrastructure of the project.

"We have completely redesigned the interface of EyeWire, we've designed a different onboarding system that's gamified, has narrative, has art that goes with it. We've built a notification system, a pop-up system, a better infrastructure for joining teams. An idea for how players could form their own teams and compete. We have reimagined how you would have an automatic level progression system. Most of the things that we've wanted to build are more on the game mechanics side." (Participant 1)

In truth, the team rarely made use of quantitative data for decision making. This was predominantly reserved for contexts in which development time would be spent on scientific needs, where players would be largely unaware of the changes made.

"We're more influenced by player feedback." (Participant 2)

"Usually if we're doing data-driven feature development or feature iteration, it's in the interests of efficiency, or proving that this is a feature that's needed." (Participant 1)

Nevertheless, this reliance on player feedback raises a number of issues. The first of these is that the team found it much easier to obtain feedback from those players who are highly engaged to the point at which they are considered "top players,", whereas there are not as effective mechanisms for eliciting these views from newer volunteers who perhaps are not as involved yet in the social side of the project. This has led to a development schedule focusing on maximising engagement from existing users and a resulting tradeoff in engagement from newer and less active players.

"We have over time probably grown more towards building more features for power players. And that has had a negative consequence of not dramatically improving our onboarding for new players." (Participant 1)

"[H]ere we're trying our best to sustain the community, give them what they need and keep the project moving forward." (Participant 3)

Moreover, a significant insight raised by the team was the difficulty in ascertaining the accuracy of feedback given by the community. Of particular interest was the anecdotal description of the introduction of the *Scythe Complete* feature, where the team had worked closely with top players to understand their views. Initially, the scientists behind the project had hoped that the new feature would increase the accuracy of results and players had expressed their interest in being able to further assist with scientific research. Ultimately, however, the feature went unused as players preferred the better rewarded task interactions, with a greater bearing on their leaderboard ranking and point score.

"[Our mistake] was to listen to what people say, not what they do. The players were enthusiastic about it, they thought it was cool. [But] they like to say that they don't play for points, but they do" (Participant 1)

Table 6. Summary of Interview Findings

Theme	Finding	Respondent
Decision Making	Limited time and resources available to VCS games compared with other genres	1, 4, 5, 6
Decision Making	Player feedback, understanding how features perceived more valuable than player statistics	All respondents
Decision Making	Feedback easier to elicit from most active players—leads to development focused on this group	All respondents
Decision Making	Player feedback does not always match reality of player behaviours	1, 2, 3
Game Elements	Players prioritise tasks with greater rewards/point scores	1, 4, 5, 6
Rewards	Rewards (e.g., points) lose value over time as players accrue greater numbers	1
Rewards	Progression hard to introduce—no final goal to achieve or obstacle to overcome	1, 5, 6
Rewards	Individual reward elements do not make task into game	2
Rewards	Social interaction effective at breaking up monotonous tasks	All respondents
Rewards	In games, less rewarding/fun tasks abandoned, regardless of importance for project	1, 2, 3
Game Evolution	Individual game elements insufficient to motivate long-term engagement	1
Game Evolution	Competition between players promotes long-term engagement	1, 4, 5, 6
Game Evolution	Players can moderate game and chat activity effectively	1, 5, 6
Game Evolution	EyeWire evolution based on gut instinct, player feedback—not observation of other games	1, 3, 4, 5, 6
Game Evolution	Limited resources lead to slower rate of feature introduction	All respondents
Monitoring Impact	Interaction with/observation of players sufficient to understand impact of features	1, 3, 4, 5, 6
Science vs. Game	Projects must balance science and scientist needs with player needs	All respondents
Science vs. Game	Introduction of improved features can be demotivating	2, 3
Science vs. Game	Slow progress of science negatively impacts on volunteer intrinsic motivations	1
Science vs. Game	Fun games not necessarily efficient or cost-effective	1, 4, 5, 6
Science vs. Game	Scientific needs limit features which can be added to games	All respondents

5.3 Game Elements

Throughout the interviews, our focus was on understanding how and why the participants selected gamification elements to add to the project. The main elements whose use was described by the interviewees were points, leaderboards, and badges. However, additional game features, including chat, competitions, and accuracy bars (for showing performance) were also discussed.

Points, generally a crucial aspect of games and required for other game features, were described in all interviews as the fundamental element that drives the game within EyeWire.

"The most important? Probably, you know, points is up there. . . . because you know, your core task in EyeWire is to map a branch of a neuron from one side of the cube to the other and the reward that you get for doing that cube is you get points." (Participant 1)

"Anything that contributes towards your points score is definitely more incentivised than things that don't." (Participant 4)

However, whether or not the use of points is seen as an effective means of increasing engagement is uncertain. While the respondents were positive about their influence on driving a certain portion of the player-base to engage, it was not clear how effective they were for all players. In particular, it should be noted that EyeWire is very much a point-based game. Points were a fundamental part of EyeWire from the very earliest phases of the game and at no stage had the team conducted comparative testing on the effectiveness of other, less extrinsic elements. Rather than drawing on any specific evidence, the team's opinion on the use of points predominantly stemmed from their views of participant motivations:

"Are they motivated by points? Are they motivated by joy? Are they motivated by the community? I think that we have players that are motivated by all of these categories." (Participant 2)

"I think people like the points score the most, not just because it's on the leaderboard, but because it's kind of the core interaction that they're familiar with, but also you can... It's a value that can accrue the fastest in a sense." (Participant 5)

Overall, the EyeWire team expressed the view that they felt participants in VCS games expect to be sufficiently rewarded for their time and effort. It was this philosophy that drove many of the subsequent decisions to implement and modify features. Elements such as badges were added to reinforce the impact of earlier reward systems, ensuring that players did not exhaust the point systems. The team expressed the concern that accumulating points with no sense of getting closer to any victory would not otherwise provide the motivation to continue, requiring the introduction of further elements to encourage engagement with the project over a longer period of time.

"Any game, if it's a game, generally speaking needs to have a reward system." (Participant 4)

"[P]oints can be... They can seem a little arbitrary and you know, once you have tens of thousands of points, you know what's another one or two hundred that you get from doing a cube? So we introduced badges." (Participant 1)

However, this raises something of a contradiction. A common theme expressed by the team was the limited development time available for the project. Conversely, by the participants' own admission, iterative development was required to regularly produce new badges, or achievements, that players can play towards and remain engaged. Participants suggested that this reliance on reward mechanisms was largely due to the difficulties perceived by the team in modifying the scientific task to allow progression or introduce narratives:

"Some of them, [the ultimate aim] is just ultimately winning. In our case it's points, you get to be above your other peers in showing how successful you are. Because you can't really win EyeWire." (Participant 4)

Nevertheless, the team did describe a small number of progression-based features. In particular, this lack of an opportunity to win led the team to introduce smaller goals and forms of progression—specifically, competitions and accuracy bars displaying a percentage accuracy score for each player. While the developers believed that players were motivated a lot by the accuracy bars that EyeWire uses to display the "quality" of a user's contributions, this feature caused mixed effects as players became more concerned with maintaining a good score on this as opposed to completing certain types of work. The team found it apparent that different levels were required in games to ensure that players of different ability and experience may play the game in a way that is most fulfilling for them, while experiencing a feeling of progress. At the same time, they expressed the belief that players would lose motivation if they felt their own scores would be affected by the ability of others in the game, and so care had to be taken to ensure that similarly experienced users were grouped together. This was not an easy task given the need to maximise contribution levels from players and to ensure players were not unneccessarily prevented from contributing to the game.

"[T]here is some issues with accuracy being shown, in that certain higher ranked players prefer not to play on easier cells, because they're more likely to be compared with lower ranked players. And that can temporarily affect their accuracy." (Participant 5)

It is notable that many of the features described supplemented, rather than augmented the EyeWire task. The team themselves raised this issue multiple times during the interview process. Questions like what is a game and what do players expect from a game experience were crucial to the team, not only in design but also in the daily running of EyeWire. In particular, the team made the comparison with other citizen science games—notably FoldIt and EteRNA—which they felt had the look and feel of a game, while still retaining the core of citizen science activities. In comparison, despite the perceived value of the game elements introduced to EyeWire, the team nonetheless remained concerned that there were issues surrounding the tasks assigned to players—specifically, that it remained relatively "dry" and work-like.

"We call it a game, but is it a game?… I think there are some games, ETERNA, for instance, that feel like a game. It literally feels like a great game on the internet, it's engaging, the graphics are cool, the interaction is really fun … " (Participant 2)

Arguably one of the most successful features as perceived by the team was ultimately not a game feature at all, but rather one introduced to assist players in helping one another contribute to the game. The team's perception of player use of the chat feature was highly positive and they noted that it was one of the key elements in overcoming the work-like feel of EyeWire. In fact, the team's perception of chat and its importance for players was so great that they had introduced a *trivia* competition class solely to encourage chat participation—even though the competition itself yields no scientific data.

"I'd have to say chat, because with a small community they get to know each other and it kind of makes up for maybe the dryness of the default work that we're having them do" (Participant 3)

"We also have our trivia, which happens during those competitions that has absolutely nothing to do with game play itself… It gets people excited to talk to each other" (Participant 5)

5.4 Game Evolution

We were particularly interested in eliciting from the team how the game has changed over time and whether there were any procedures that were followed before deciding to introduce a new game element or feature. We have already covered the introduction of new sets of badges to increase the motivation for players who have already collected all of those available, but there were other changes that were discussed related to this topic.

The initial version of EyeWire was relatively rudimentary with few features. Players could earn points and leaderboard rankings, but these would reset after each day. Ultimately, this was the extent of the early EyeWire game interface. Changes were predominantly motivated by a sharp reduction in player numbers:

"We launched EyeWire, there was a huge bump in traffic and then after like, a month it just dwindled back down and we were like 'crap, what's going on'?" (Participant 1)

In response to this reduction, the team opted to focus on introducing competitive elements to the game. The reasoning behind this introduction was twofold: firstly, the team felt that competitions were integral elements of any game and secondly, that players were eager to show that they were the best.

"[We thought] 'It's probably because we don't have any competitions!' These people expect a game. Let's give them a game." (Participant 1)

"It was kind of like an ad hoc community thing where one player was like 'I'm the fastest neuron tracer in the world'. We were like 'Oh yeah, want to back it up? Let's do a competition!' " (Participant 1)

Nevertheless, while the team believed in the effectiveness of these competitions, participant 5 explicitly stated that no effort had been made to monitor competition sign-ups. Rather, it appears that from the team's perspective, the introduction of competitions had the desired effect of reigniting interest in EyeWire. Rather than continuing and exploring other features which may have been less successful, the team instead opted to strengthen these competitive elements, adding additional infrastructure and competition models.

In addition to competitive elements and similar to recommendations made within the literature, the team implemented progression opportunities and unlockable features. Players who demonstrate high levels of accuracy are able to access new features and receive indicators of their status to display to other players. This introduction brought in the use of Seaborn and Fels' 'Roles' element, which gives players another motivation to try and progress in terms of their class (Seaborn and Fels 2015). These roles, however, were predominantly introduced to reduce the workload assigned to the team.

"As the player base proved that they were better, we adapted the game system to give them more power and we give them more power and allow them to have more features by giving them a ranked class. So they become mentors or moderators which is mentors helping other players, moderators policing chat." (Participant 1)

"Because [when] there was not a good system for giving more power to the players who were actually good in EyeWire, it meant that the burden was on us to make sure to be fixing community errors." (Participant 1)

Perhaps surprisingly, the introduction of features to the platform did not appear to follow any exact strategy. Rather than drawing on the experiences of other games or recommendations from the literature, the team instead drew predominantly on their own observations of the community's needs and specific feedback from top players.

"[we ask] what does the community need, what are they struggling with, how can we make their lives either more efficient or more enjoyable? (Participant 2)

There did not appear to be much influence from other citizen science games in terms of evidence of what game elements are effective that led to the introduction of features in EyeWire. However, it was suggested that generally the team has an awareness of what other games (not necessarily citizen science games) have and are doing:

"Thinking about what elements other games have, I'm sure that plays into what I think would be a good feature for the game." (Participant 6)

This raises the question of where the team got the idea for specific new features—for example, the reasoning behind the early decision to focus on competitions. Far from being an evidence-based process which is carefully researched and implemented, the team suggested that these decisions were predominantly "gut" decisions, based on the participants' own views and opinions. Our findings suggest this was for two key reasons: firstly because the team had negative perceptions about the genre of VCS games and secondly because of a lack of resources.

"But I would say, fundamentally, it's more due to what… Like, people here at headquarters think may sense for the game and not necessarily looking at say 'what's Foldit doing right now?'" (Participant 5)

On the one hand, this approach—according to the team—has been relatively successful in maintaining the engagement of these top participants, yet there has been less engagement from newer players and those displaying average levels of activity. Furthermore, the team described struggling with prioritising features, noting a large backlog of new elements intended to improve the game experience that had yet to be introduced.

5.5 Monitoring Impact

We also investigated how the team tracks the effects of changes and assesses whether the introduction of new game features was positive or negative. Generally, the standard player engagement statistics are examined on an ad-hoc basis to see if there were changes in player activity, and whether these were as a result of a particular change:

"[I]f we know when a certain feature was released, or whatever, we can be like 'oh that spike there was when we released this' or 'oh, we released this then, but I don't actually see much of an impact'." (Participant 4)

"We look over time at our cell completion rate and it's going up and that's good. We don't spend a huge amount of time devotedly scouring through stats and looking at engagement, churn rate and things. We've gone through periods where we've looked a lot at the stats, but the kind of takeaway has been—We know a lot of this stuff, we know the things we need to like improve a lot of these numbers. The problem is we don't have enough development time. So, we've just focused on other things." (Interview 1)

Indeed, the qualitative insights are almost more important for the team in order to understand the effects of a new feature, rather than the statistics about how much that feature is being used which appear to require too much time to track effectively. This emphasises the importance of the chat functionality on EyeWire, which provides a real-time stream of the players' thoughts on what is good or not.

"I think what is more challenging for us is understanding like the softer points of how the players are using a new feature. How they're going about reaping cubes, how they communicate with one another on a tough cube, how we can give them feedback . . . You know, just those how cases are a lot harder, but they're a lot more valuable to us, like how does a player learn to be good at EyeWire? We think it's by doing a lot of cubes. We think it's by talking to other players." (Participant 1)

Explaining further, we extracted a key insight into the mindset of citizen science players and the importance in this case of the tasks feeling like a game, rather than work:

"[T]hey sort of played around with it for a while. But then after a couple of weeks, maybe a month, they weren't really using it very much and so we just kind of started —I just started doing chat interviews with the players and I was like 'why aren't you guys using this'? And they were like 'Oh, well, we just—We dropped down on the leaderboard'. 'We're—What's the point of doing this? It just feels like work.' That was their feedback. It felt like work. And they didn't want the game to feel like work. And I think they felt like work because there was no reward." (Participant 1)

It was in response to these reports from players that the team once again turned to reward mechanisms to make tasks more motivating. Yet, we note there remain questions surrounding the extent to which rewards alone can make an unrewarding work-like task feel like a game. This reiterates the earlier point made by the team surrounding the expectations of players—players expect a game, but is that what they receive? While the team was quite confident that players did not expect the game to feel like work, they were overall less confident about where the work/game distinction might be found.

5.6 Is Science a Game?

A common theme throughout the interview process was the existence of a number of issues resulting from reconciling the needs of a game with the needs of scientific research. One tension mentioned by the EyeWire development team is the visibility of features that are introduced. The team described issues arising from the needs of the project in terms of science and the extent to which players will be aware of these changes. In particular, there was a need to reach a balance between the needs of the players and the needs of the project scientists:

"[Suggestions for] features we should improve on is sort of from two directions. We either say what does the community need… And then there's the back end side, which is the scientists at Princeton that say we need to get more work done.' " (Participant 2)

This became particularly problematic in the case of adjustments to the project that were required to increase the accuracy of submissions.

"the way that we generated the 3D meshes. It's very new geometry. They'd definitely grown attached to the old way that things look… They perceived the defects as details." (Participant 3)

"[New meshes] had fewer discontinuities in them and they were more scientifically accurate, but ironically the community had grown accustomed to the discontinuities in the old meshes." (Participant 2)

While the game itself does not negatively impact the quality of submissions, players resist efforts to improve the suitability of submissions for scientific research. This is surprising given that a desire to contribute to scientific research is a key motivation among EyeWire players, as well as VCS game participants more generally (Tinati et al. 2016).

A further tension arises from the slow rate at which scientific research advances. Players expressed unrealistic expectations of the speed at which research would progress and expressed disappointment in interactions with project scientists:

"Science goes slow. One of the players was like 'so what have you learned since last time?' And I think one of the researchers was like… 'Oh, we haven't even looked at them.' That was the truth but it made the players feel like crap." (Participant 1)

As a result of this, the team has made an effort to shield players from interacting with project scientists. This raises questions about the extent to which participation in science is truly motivating for citizen science participants. Rather than altruistic contributions to science research more generally, observations from EyeWire suggest that players are motivated by contributing to specific scientific discoveries and research outcomes.

A related third and more complex issue concerns the extent to which a successful game is a successful scientific methodology.

"There was definitely a push to make EyeWire more efficient than it currently was. Because for a time, when you really did the maths, it was like… The amount of money that was being put into… Like… Paying employees to run the citizen science game itself was more than the money being put into paying tracers at Princeton to just do it themselves and the quality of the data was not necessarily better on our end." (Participant 5)

"Have people heard of this, are they interested in it? And then whether or not the project is successful in producing something. There's certain kind of degrees of where you find a project successful." (Participant 4)

A repeated concern expressed by all members of the team was the tendency that players showed to request features that were neither suitable nor feasible for a citizen science game.

"[Players] are very vocal and we usually have a list of things we have to do." (Participant 7)

"Our problem is … based on trying to get outsiders to help offer kind of new game ideas is that we have various… a lot of restrictions on how we need to do things to kind of get accurate scientific results." (Participant 2)

These findings suggest a further potential data quality issue arising from citizen science games. If the EyeWire project is to be financially and scientifically viable, the team must make every effort to maximise the quantity of contributions made to the project. At the same time, to truly maximise contributions, the team faces compromises in terms of the features available in projects and the accuracy of the submissions gathered from players. Moreover, balancing the needs of two different communities—players and scientists—is an important, but complex process. Many of the changes introduced by the team were ultimately one-sided, addressing the needs of players with little impact on project outputs or alternatively ensuring the accuracy of submissions while impacting on player engagement.

In the case of EyeWire, at least, while the scientific activity can be made into an engaging and challenging game, our findings suggest that contrary to motivational findings suggested by the literature, it is the game elements—points, rankings, and progression—that attract and maintain the interest of players.

6 DISCUSSION

We have investigated the use, reporting of, and effectiveness of gamification elements in VCS. Within this article, we have provided three contributions: (1) a review and summary of existing literature into gamification effectiveness for VCS, (2) an overview of what game elements are used in VCS projects, and (3) findings from interviews carried out with the EyeWire project team to understand more about how these elements are introduced to the game, tracked, and assessed to determine their performance.

6.1 Gamification, Engagement, and Motivation

Overall, our findings suggest that gamification and the use of game elements *supports* rather than replaces other motivational factors which are common in less gamified projects. Previous research has identified altruistic motivations as important factors in encouraging players to return to projects and shifting from short-term to long-term contribution patterns (Crowston and Fagnot 2008; Rotman et al. 2012). While the literature review process provided some evidence that game elements have a similar effect, this was not supported by all sources and moreover, the EyeWire team suggest that extrinsic reward factors such as points can be demotivating in the long term as players gain increasingly more and such rewards lose context. In fact, experiences that evoke negative emotions—emotions such as distress or sadness—have been suggested to nevertheless motivate player participation in games, if the players feel that they can make a difference through their participation (Iacovides and Cox 2015). This suggests that altruistic motives are more significant than extrinsic factors and "fun"' for long-term participation.

Furthermore, the literature demonstrates that it is intrinsic factors—specifically interest in the underlying research topic, field. or in science itself—that is the single biggest driver of participation in citizen science. This is not to suggest that extrinsic factors and game elements do not have any inherent value for volunteer motivation, as the EyeWire team suggest that game elements were highly effective for their "power players" and had a positive effect in terms of player retention and project efficiency. However, these elements enhance, support, or otherwise compliment players' intrinsic interests and the way in which players perceive tasks, rather than replacing such factors. In this way, game-based projects are similar to non-gamified citizen science intiatives, which rely heavily on players' own interests (Wiggins and Crowston 2011). Nevertheless, there is some evidence in the wider gamification literature to suggest that framing tasks as games can make them more interesting and enjoyable, potentially impacting on players intrinsic motivations. Lieberoth (2015) demonstrates that even the simple act of framing a task as a game is as motivating for participants as the introduction of game elements themselves, although these elements were also suggested to be intrinsically motivating.

Nevertheless, there is a complex interplay between the motivations demonstrated by citizen scientists and we suggest that introducing extrinsic factors to tasks which rely on participants' altruistic or intrinsic motivations can have unexpected effects. In particular, we note the example of EyeWire's Scythe Complete feature, which while of great importance to the project and which was framed in a highly altruistic manner, was nevertheless avoided by players who suggested that it was not fun and offered poor rewards. The team similarly suggested that activities offering higher rewards and point scores receive more attention from players than those which do not, even though in previous studies of EyeWire players have described their motivations as predominantly intrinsic or altruistic (Tinati et al. 2016).

Our findings also contribute to the discussion surrounding the use of competitive and collaborative elements in gamified citizen science projects. While competitive elements appear to be somewhat more common—and in some games, such as EyeWire, form the backbone of gameplay—players as a whole are more engaged by opportunities for cooperation and for social interaction. Nevertheless, different groups of players respond differently to competition and highly active and younger players have been suggested to be more engaged by competitive elements than by collaboration. This suggests a potential tradeoff between the needs of a high performing minority and a larger, but less active minority. Nevertheless, mid-performing players may also be motivated by competing with themselves through leaderboard and point features, even if not otherwise engaged through competition with other players, and these features may also contribute to "normalising behaviours," where players feel a (self-driven) social pressure to do their fair share of the work (Preist et al. 2014). It is unclear from the literature to what extent this phenomenon is unique to gamified and game-based projects. While on the one hand, building relationships with fellow players and scientists and collaborating with the community towards common goals have been identified by players as key factors motivating their participation in citizen science (Nov et al. 2011; Rotman et al. 2014), participants in Galaxy Zoo and other Zooniverse projects did not describe social interaction as a strong source of motivation (Cox et al. 2015; Raddick et al. 2013). This is perhaps surprising, given that sociality was more common during our project survey among those projects which did not describe themselves as games than those which did.

It should be noted also that gamification is not a "one size fits all" solution to the problems associated with motivating and engaging citizen scientists in project activities. As demonstrated by our literature review findings, participants who are highly intrinsically motivated and those who are less active or less motivated respond poorly to gamified elements, either because they are perceived as trivialising serious and otherwise motivating tasks, or because they introduce stress and high levels of competitiveness that participants cannot hope to match. However, our findings also suggest that such features also have no effect on average performing users–a group characterised by interview participants four and five as "lurkers" who respond neither positively nor negatively to the introduction of game elements.

6.2 Use of Gamification in VCS

The most popular game elements used within the surveyed projects were fairly straightforward. Points and leaderboards were commonly used, adding game mechanics to certain tasks and introducing some form of competition. These features were commonly assessed in other studies summarised earlier in this article. However, their complexity in terms of gameplay and engagement is limited, which suggests that there are still opportunities for development.

Our findings show that recommendations and best practices from the literature are not always followed when VCS games are designed and implemented. For example, in spite of the importance associated with altruistic and intrinsic motivational factors in prior studies, these motivations are not necessarily present when considering the features implemented within projects. While the surveyed games demonstrated a high proportion of altruistic framing, such features were absent in non-game projects with gamified elements. VCS games also demonstrate a tendency to make use of competitive elements, in contrast with recommendations from the literature, which suggests that volunteers respond more positively to collaborative and team-based activities.

One possible explanation for the difference between the theory of literature findings and the practise of project design is the relative simplicity of implementing features. The interview findings suggest that some of the features that are most appealing to players, such as narrative framing and progression opportunities, were time-consuming and difficult to implement, due to an incompatibility with VCS contexts—in particular, the lack of a feasible ultimate goal to reach or issue to overcome. Similarly, there is the tendency for reward elements such as points and badges to eventually reduce in value as players exhausted the games reward scheduling, requiring further effort from developers who must implement further mechanisms.

At the same time, more advanced game elements would require both expertise within the project team and an engaged community to demand them. For example, we noted from the existing literature that story-based games could be more interesting for some groups of users (Prestopnik and Tang 2015), yet the use of narrative was rare in the projects that we surveyed (Figure 5). Shaping a game around a narrative could be seen as a considerably bigger development task, predominantly as unlike other "features" narratives are far more complex and of much more significance—framing both the task and all other features. This was particularly problematic especially when there are restrictions on many of these projects to ensure that they are still scientifically useful—as discussed by the EyeWire team. Due to the relatively low use of narrative so far, it seems that there remains an untapped potential to frame game tasks around some kind of story, which could go some way to reaching those citizens who are not motivated by points or competition. In particular, our findings suggest that these more intrinsically motivated players are currently less well served by VCS games than those who enjoy extrinsic rewards.

EyeWire makes use of different player roles as a way of demonstrating experienced players' advanced status in the game and appealing to various types of motivations. However, in the projects we surveyed, both status and roles were not used to a great extent, and different player roles were not the focus of any of the papers presented in Table 7. Even in EyeWire, the decision to introduce these roles was predominantly motivated by the need to increase the efficency of the project and to pass more time-consuming activities into the hands of players. Nevertheless, having these sorts of elements can give players something to work towards, and a reward for doing so, in a similar manner to badges. It is therefore surprising that this element has not been used to a greater extent among other projects, given that it represents a form of progression that is easier to introduce than, for example, levelling systems or narrative arcs. Future research could look into tracking the effect of its introduction. Indeed there are numerous opportunities for carrying out this form of analysis on new elements, where, for example, A/B testing could be used to demonstrate whether a particular change has a desirable effect. Again, referring back to the papers in Table 7, very little existing literature has taken this approach.

Interestingly, the findings from both the existing literature and the interviews carried out in this study point towards much of the development in VCS games going towards maintaining an existing community of players. The EyeWire team spoke about adding new features for their "power players" and based on feedback from those already playing to sustain the community. This echoes and may partially explain a number of literature findings such as Iacovides et al. (2013) which (by studying EyeWire along with Foldit) found that gamification was useful for sustaining engagement but had less of an effect for attracting new volunteers. As noted, newcomers to VCS projects are predominantly motivated by their own altruistic and intrinsic interests in science, but our findings suggest that many gamified projects lose sight of this. While altruistic framing devices were relatively common, there was a key distinction in non-gaming contexts, where the use of gaming elements occurred mutually exclusively with altruistic framing. This may explain the tendency that gamified projects like Old Weather observed among new players leaving the project relatively early (Eveleigh et al. 2013).

Based on these findings, we make the recommendation that VCS games and particularly gamified projects should employ a range of motivational affordances. In their current state, many of the surveyed projects and literature findings suggest that some groups of players are not well represented in terms of the design decisions made by designers to satisfy players—particularly those players who are more intrinsically motivated by the urge to engage with science. Such an effort would have beneficial effects not only for attracting and maintaining player engagement, but also for ensuring the accuracy of project outputs (Mekler et al. 2013).

6.3 Analysis of Gamification Effects

From the literature, it was apparent that although gamification is becoming increasingly discussed within VCS, there is still little coverage of the tracking of specific game element performance. The general perception in the studies presented in Table 7 is that game elements tend to have a positive impact, but in some cases this is challenged, with some suggesting that the use of competitive features—as well as others—can put off certain players (Eveleigh et al. 2013). However, it is unclear whether in general this effect is true, or whether the projects themselves have deeper insights into what impact the different elements do have. From the interviews with the EyeWire team, we found that this analysis was carried out only to a small extent by looking back over player engagement data and whether changes in activity appeared to follow a particular change to the game, rather than tracking the effect of the new element at the time. Instead, change tracking is carried out qualitatively, using insights from the chat feature which allows a two-way feedback mechanism, and can ensure any potentially bad effects are negated quickly. It should be noted nonetheless that comparative analyses of the impact of features—for example, collaborative vs. cooperative activities—were not carried out by the team, in part due to a lack of available resources.

The importance of tracking changes was underlined in the EyeWire interviews when the experience of listening to what the community says, rather than observing what it does, was shown to sometimes be unreliable—especially if a change fundamentally reduces the feeling that the project is a game, or if it causes existing players to start appearing worse. This is a compelling insight, as it suggests that the community around EyeWire *is* there because of the gamified nature of the project, and their motivation is affected when changes subsequently reduce this experience, which would support the findings of numerous papers discussed earlier where points were argued to be engaging features that helped to sustain engagement (Iacovides et al. 2013; Mekler et al. 2013; Siu et al. 2014). At the same time, this raises questions about the findings of a number of the surveyed publications, which rely on surveys and interviews with VCS players. We suggest that further analysis of these contexts—that is, motivation and engagement—is required to clarify the effect that more intrinsic and altruistic features have on player engagement, when compared with extrinsic point and reward systems.

Our findings also suggest a number of potential issues in applying game framing and activities to scientific research contexts. While the accuracy of data submissions has been shown to generally be comparable with non-gaming contexts, there remains a question of the development time and effort required to attract and sustain player populations. In EyeWire, the team made frequent note of the various requests made by players and the negative reaction many players had to changing features—regardless of the intention behind the change or the scientific needs which motivated such changes. Similarly, it would suggest that removing game elements that have been used by an established community such as in EyeWire would have a detrimental effect, comparable to those impacts reported in enterprise social networks (Thom et al. 2012). This tradeoff in balancing the needs of game players with the needs of project scientists is an interesting area for further research that was not significantly explored in the literature surveyed.

6.4 Game and Non-Game Distinction

Overall, our findings suggest that the distinction between those projects which describe themselves as games and those which do not is not well established. On the one hand, there were certain common trends among the two groups—with non-gaming projects being more likely to include opportunities for collaboration, learning, and altruistic framing, while gaming projects were more focused on extrinsic motivations. However, no features were specific to only one type of project and despite not describing themselves as games, many of the "non-game" projects analysed within our survey featured gamified elements such as points. Moreover, within this non-game category, two clear subtypes emerged—gamified projects, which share many common features with games, with almost exclusively extrinsic features such as points and leaderboards and non-gamified projects, which rely on participants' altruistic intentions.

Yet even among those projects which explicitly describe themselves as games, the extent to which the activities assigned to players resemble a conventional game varies. As the EyeWire team stated, some VCS games better resemble work activities, while others, like EteRNA, very much have the look and feel of a game. The question of how to define a "game" is therefore a key question within this area—or to paraphrase the interview participants: is it simply enough to describe an activity as a game? Moreover, is it enough to simply add game elements to an inherently work-like task?

Across our three studies, we have found that VCS games are predominantly defined by restraints such as the limited resources available for development and commonalities such as the motivations of volunteers. Nevertheless, in its current state, the genre is not sufficiently defined to warrant specific expectations of what a VCS game might encompass, either in terms of features, or in terms of the activity and experience provided to players. Our interview findings suggest that for EyeWire at least, this was problematic, both for players and for designers, who struggled to meet the expectations of the player base. Similarly, while the surveyed literature included some consideration of the effects of game framing, there was little in the way of exploration of the impact of specific game activities—for example, puzzle solving—when compared with non-game tasks combined with features such as points.

For this reason, we believe that a key future research area should be ascertaining and exploring the expectations of project volunteers with regard to game and non-game experiences. Given the tendency of EyeWire volunteers to request and even expect new features which were incompatible with citizen science contexts, we identify a need for greater understanding of the inherent opportunities that citizen science provides for game play. Such research findings would be of significant value to the EyeWire team and, we believe, to other researchers looking to make use of gamification to modify crowdsourcing and human computation tasks.

6.5 Limitations and Future Work

Overall, it seems that the attitude towards gamification in citizen science is that it does generally have a positive effect, and as with its use in crowdsourcing, future studies now need to address which specific design choices bring about its success (Morschheuser et al. 2017). As mentioned above, there is an opportunity to further study the introduction of particular game elements to existing projects, following A/B testing or other means, to determine their overall effect on players. Currently, the work done to track the effectiveness of particular elements appears limited, and without deeper insights here there will continue to be a lack of understanding about how best to employ them. Forde et al. (2016) have planned a more in-depth study on the effects of individual game elements, and gamification in general, on the Fylo (Fake Phylo) project, following their original research which produced quantitative data that showed no effect, while qualitative insights suggested the game elements were important. Our findings support their plan, along with their argument for the need to study the area in more depth.

While this study has attempted to establish the current perspectives in existing literature and projects, we appreciate that focusing on one VCS game for the interviews only provides a limited window onto the wider VCS scene. However, we believe that the views and experiences of the EyeWire team reflect many of the discussions put forward in existing literature. Furthermore, while we have analysed existing research for insights into the effects of gamification, we recognise that a large-scale study across multiple projects and looking at longitudinal engagement data has yet to be conducted.

In addition, one remaining area of ambiguity is in the impact of game elements on players intrinsic motivations and the effect this has on the recruitment of participants. Our findings suggest that game elements have little impact on a players' initial decision to contribute to a project and that this decision is made based on a players' own intrinsic interests. However, there are some suggestions in the literature that extrinsic factors and game elements have a moderate effect on players' intrinsic motivations. It is also notable that due to the nature of VCS, there has so far been little opportunity for A-B testing to compare the importance of science and scientific framing with the impact of game elements and game-like framing. We nevertheless suggest that this is an interesting area for further study which could be incorporated into the research process when comparing the effectiveness of individual game elements.

7 FINAL REMARKS AND CONCLUSIONS

This article has provided a range of insights into the use of gamification within VCS projects. While success in citizen science has been discussed before, there has yet to be the same examination of what constitutes effective use of game elements in these projects. We provide an overview of the literature reporting on the use of individual elements and projects, and summarise the current landscape with regard to gamified VCS. We explored these insights further through the interviews with the EyeWire project team, and found that there appears to be significant focus on maintaining and satisfying existing communities, rather than reaching new players, and that development of such features that would motivate new users is hindered by resource limitations compared to traditional game studios. Our findings have demonstrated that the impact of gamification and game elements on VCS projects is complex—while active and engaged players are highly motivated by extrinsic and game factors, those players who are more driven by intrinsic motivations perceive game elements negatively. Moreover, while extrinsic factors may support long-term participation, intrinsic motivations and altruism remain important drivers for initial participation and the switch to long-term engagement patterns within VCS. For this reason, game elements should not be used alone, but should rather be introduced alongside framing devices that support other motivations such as opportunities for learning and indications of the value of players' contributions for scientific research. We envisage that the use of game elements in VCS will continue to rise; however, it is clear that more robust tracking and analysis mechanisms are required in order to truly understand the impact of each particular feature.

ACKNOWLEDGMENTS

We thank the EyeWire project team for their participation in the interviews for this research and the anonymous reviewers for their constructive and invaluable feedback.

APPENDIXES

A SUMMARY OF LITERATURE REVIEW PUBLICATIONS

Table 7. An Overview of the Findings in the Literature about Gamification Use in Citizen Science Projects

Study	Project	Method	Game Element or Features Assessed	Psychological Outcome	Behavioural Outcome	Positive/Negative Impact of Gamification
Bowser et al. (2013)	Biotracker	Field Study (N=71)	Badges; Leaderboards	Game elements increase motivation to participate.		Positive
Carlier et al. (2016)	Ask'n'Seek	Web-Based Study (N=162)	Game Framing		Competition leads to reduced level of contribution; higher level of accuracy (relative to paid crowdsourcing)	Mixed
Chung et al. (2017)	Matchmakers	Web-based Study (37)	Visual Load		Cumulative Score and successful game completions higher with greater visual load	Positive
Crowston and Prestopnik (2013)	Happy Match/ Citizen Sort	Web-based Experiment (N=200)	Points;	Some reported motivation to play the game.		Neutral
Curtis (2015)	Foldit	Survey (N=37); Interview (N=10)	Points; Competition; Cooperation; Sociability; Tutorial;	Participants believed they were making an important contribution to science. Little motivation from points and ranking mechanics.		Mixed: positive for less-traditional elements such as chat; less so for points and leaderboards.
Eveleigh et al. (2013)	Old Weather	Survey (N=545); Interview (N=18)	Progression/Status; Leaderboards; Competition	Motivates some volunteers.	Competition leads to casual participants leaving.	Mixed
Forde et al. (2016)	Fylo ("Fake Phylo")	Web-Based Experiment (N=67)	Points, score bar, accuracy	No significant differences from gamified version in terms of intrinsic motivation, competence, and autonomy.	Game elements were informational and useful for adapting behaviour.	Mixed

(Continued)

Table 7. Continued

Study	Project	Method	Game Element or Features Assessed	Psychological Outcome	Behavioural Outcome	Positive/Negative Impact of Gamification
Goh et al. (2010)	Bespoke Experiment	Lab Study (N=66)	Genre—Cooperative vs. Competitive		Competitive activities lead to significantly higher numbers of tags and tag quality.	Mixed
Greenhill et al. (2016)	Zooniverse	Participant Observation	Extrinsic Rewards	Participants motivated by both intrinsically interesting and scientifically valuable tasks and extrinsically rewarded "just for fun" tasks		Mixed
Huang and Fu (2012)	Bespoke Experiment	Web-Based Experiment (N=150)	Game Framing; Feedback; Social Interaction		Game framing and feedback both lead to increase in contribution levels—particularly when combined. Social interaction increases participation levels, but to slightly lesser extent	Mixed
Iacovides et al. (2013)	Foldit, EyeWire	Interview (N=8)	Cooperation; Sociability; Leaderboards; Points	Participants wanted to feel they were making a difference; felt that evidence of project progress was rewarding; chart and forums increased sense of community.	Points and leaderboards extend sessions. Team-play led to continued engagement.	Positive for sustaining engagement, no effect for attracting new volunteers
Iacovides and Cox (2015)	Medical Student Errors; Nurse's Dilemma; Patient Panic; St. Error Hospital	Player Evaluation (N=12)	Game Framing	Serious activities as games motivates players through development of empathy and emotional connection.		Positive

(Continued)

Table 7. Continued

Study	Project	Method	Game Element or Features Assessed	Psychological Outcome	Behavioural Outcome	Positive/Negative Impact of Gamification
Kapenekakis and Chorianopoulos (2017)	Bespoke mobile app	Field Study (N=13)	Points	Some users motivated to find new routes, and moderate bad behaviour.	Many players didn't add road tags, despite generous offer of points.	Generally positive
Laut et al. (2016)	Brooklyn Atlantis	Web Study (N=53,090)	Competition (through virtual peer)		Participants adjust performance based on that of their virtual peer, and contributions can be increased.	Positive
Lieberoth (2015)	Bespoke Experiment	Lab Study (N=90)	Framing	Framing tasks as games increases participant motivation even regardless of game features		Positive
Mekler et al. (2013)	Bespoke experiment	Web-Based Experiment (N=172)	Points; framing	Points and framing both increased intrinsic motivation.	Using points generated more tags; more time spent per tag when meaningful framing was combined with points; framing increased tag quality.	Positive
Pedersen et al. (2017)	Quantum Moves	Web-Based Experiment (N=4553)	Leaderboards		No statistically significant impact on player retention or accuracy of submissions	Mixed
Ponti et al. (2015)	FoldIt, Galaxy Zoo	Interviews (N=24); Content Analysis (N=650,000)	Points; Status	Point scores motivate participation for some players; others demotivated due to use of scripts to automate processes.	Public status announcements lead to cheating behaviour and low-quality submissions.	Mixed
Preist et al. (2014)	Close The Door	Field Study	Points; Leaderboards	Leaderboards most motivating for top players. Average players motivated by normification and personal pressure to contribute to work.		Mixed

(Continued)

Table 7. Continued

Study	Project	Method	Game Element or Features Assessed	Psychological Outcome	Behavioural Outcome	Positive/Negative Impact of Gamification
Prestopnik et al. (2014)	Forgotten Island, Happy Match	Web-Based Experiment (N=900)	Points; Narrative		Story-based game introduced more cheating behaviour, without severely impacting volunteer accuracy. Volunteer retention better in points-based game.	Generally positive
Prestopnik and Tang (2015)	Forgotten Island, Happy Match	Lab Experiment (N=27)	Points; Narrative	Story-based game more interesting; points-based games that focus on the science less appealing to those intrinsically motivated.		Positive
Prestopnik et al. (2017)	Forgotten Island, Happy Match	Web-Based Study (N=4,174)	Narrative, Game Framing		Narrative-based game leads to reduced participant retention; no significant difference in data quality, in spite of cheating in narrative-based game.	Mixed
Sabou et al. (2013)	Climate Quiz	Web-Based Study (N=648)	Game Framing		Game interface leads to significant increase in task skipping and significant increase in project completion time; Game framing increases accuracy of submissions compared to paid microtask crowdsourcing.	Mixed
Siu et al. (2014)	Cabbage Quest (GWAP)	Web-Based Experiment (N=118)	Points; Competition; Cooperation	Participants reported greatest engagement with competitive option.	Collaboration focus increases accuracy, whereas competition increases speed.	Positive

(Continued)

Table 7. Continued

Study	Project	Method	Game Element or Features Assessed	Psychological Outcome	Behavioural Outcome	Positive/Negative Impact of Gamification
Siu and Riedl (2016)	Cafe Flour Sack	Web-Based Experiment (*N*=78)	Extrinsic Rewards; Points; Leaderboards	Players more motivated when allowed to choose rewards.	When choosing rewards, player accuracy, number of contributions, and contribution speeds greatly increase.	Positive
Siu et al. (2017)	Gwario	Lab-Based Study (*N*=64); Survey (*N*=64)	Competitive vs. Cooperative Gaming	Players more motivated by competitive gaming.	Cooperative games lead to slight increase in submission accuracy but significant increase in task completion time.	Mixed
Thaler et al. (2012)	OntoPronto	Web-Based Study (*N*=270)	Game Framing		Game-based activity leads to increase in number of contributions but reduced submission accuracy.	Mixed
Tinati et al. (2017b)	EyeWire	Survey (*N*=1365)	Sociability (real-time chat)		Players establish collaborative mechanism without formal features for these activities.	Positive
Tinati et al. (2017a)	EyeWire	Survey (*N*=1505)	Learning, 3D Interface	Players predominantly motivated by altruistic desire to assist science, intrinsic interests in science, and having fun.		Positive

B SURVEYED PROJECTS

Table 8. Projects Surveyed for Game Element Usages

Project	URL	Domain	Game
Agent Exoplanet	https://lco.global/agentexoplanet/	Astrophysics	No
Age Guess	https://www.ageguess.org/	Biology	Yes
ARTigo	https://www.artigo.org/	Art History	Yes
Asteroid Vesta	https://cosmoquest.org/x/science/vesta/	Astrophysics	No
Asteroid Zoo	https://www.asteroidzoo.org/	Astrophysics	No
Brooklyn Atlantis	https://cb.engineering.nyu.edu/participate	Environmental Monitoring	No
Cities at Night	https://crowdcrafting.org/project/nightcitiesiss/	Astrophysics	No
Disk Detective	https://www.diskdetective.org/	Astrophysics	No
EteRNA	http://www.eternagame.org/	Biology	Yes
Explore the Seafloor	http://ets.wessexarch.co.uk/	Biology	No
EyeWire	https://eyewire.org/	Neurology	Yes
FoldIt	http://fold.it	Biology	Yes
Galaxy Explorer	https://www.galaxyexplorer.net.au/	Astrophysics	No
Galaxy Zoo	https://www.zooniverse.org/projects/zookeeper/galaxy-zoo	Astrophysics	No
Geo-Wiki	https://www.geo-wiki.org/	Environmental Monitoring	Yes
Mark2Cure	https://mark2cure.org/	Biology	No
McMaster Postcard Project	https://postcards.mcmaster.ca/	History	No
Moon Mappers	https://cosmoquest.org/x/science/moon/	Astrophysics	No
Old Weather	https://www.oldweather.org/	Climatology	No
Phylo	http://phylo.cs.mcgill.ca/	Biology	Yes
Play to Cure: Genes in Space	http://www.genes-in-space.org.uk/*	Immunology	Yes
Reading Nature's Library	https://www.zooniverse.org/projects/mzfasdg2/reading-natures-library	Various	No
Reverse the Odds	https://www.oncology.ox.ac.uk/page/reverse-odds	Immunology	Yes
Smithsonian Transcription Centre	https://transcription.si.edu/	Various	No
Smorball	http://smorballgame.org/	Botany, History, Zoology	Yes
Socientize	http://www.socientize.eu/?q=eu	Various	Yes
Stupid Robot	http://www.tiltfactor.org/game/stupid-robot/	Humanities	Yes
The Skynet	http://www.theskynet.org/	Astrophysics	No
VerbCorner	https://archive.gameswithwords.org/VerbCorner/	Linguistics	Yes
Weather Detective	http://www.weatherdetective.net.au/*	Climatology	No
Wildsense Tigers	http://www.wildsense.org/	Ecology/Conservation	Yes

* = Project no longer available at time of publication.

C INTERVIEW QUESTIONS

C.1 Participant Introduction

(1) Could you begin by introducing yourself and your role in the team?
(2) What is your interaction with other members of the team like?

C.2 Use and Introduction of Game Elements

(1) What are the most important game elements that you use in your project?
(2) How effective do you think these elements have been?
(3) When introducing new features, do you base your development lifecycle on features you know work in other games, or your own insights about how players use your own platform?
  (a) Please discuss how has this changed over time.
  (b) Are there any features or elements that you've considered introducing but subsequently haven't done so and if so, why?

C.3 Feedback on New Features

(1) After implementing a new feature, what is your process for receiving feedback on it from the community?
  (a) How do you review and act upon that feedback?
  (b) What is the relationship between data analytics on the platform and the way in which you re-engineer features, compared to when you speak to the community?

C.4 Effect Analysis

(1) When looking at effects on user engagement or motivation, do you study this longitudinally, or just at a single point in time?
(2) When things go wrong, or badly, what process do you follow in order to pinpoint exactly what caused the problem?

C.5 Success in Citizen Science and Games

(1) What do you think makes a CS project successful?
(2) What are your measures for success?
(3) What do you think makes a game successful?
(4) Do all the aspects you've described previously apply to creating a successful CS game? If not, why?

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Received June 2017; revised April 2018; accepted April 2018