To Help or Hinder: Real-time Chat in Citizen Science

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Abstract

In this paper we investigate the implications of providing a real-time messaging interface in a Web-based citizen science game. Our study draws on data from two weeks of chat messages and survey responses collected from Eyewire, a highly successful citizen science game which enables players to take part in scientific enquiries, within a semi-gamified environment. Our analysis reveals that real-time chat facilitates and supports players for several types of engagement; to collaboration on tasks, knowledge sharing, learning, socialising, supporting other in the community, and to help sustain long-term participation. Based on the analysis, we derive a set of design recommendations for citizen science platforms designers, focusing on the role of real-time chat on improving participation and performance.

Introduction

Web-based crowdsourcing has become a well-established method to transform computationally difficult and expensive problems into time-efficient, scalable solutions. It can mobilise large groups of people, both skilled and untrained, to carry out significant amounts of work quickly and efficiently (Brabham 2008), and has been applied to anything from curating online encyclopedias (Hill and Shaw 2013) and computing data analysis at scale (Lintott and others 2009; Anderson et al. 2002) to creating extensive digital libraries (von Ahn, Blum, and Langford 2004). In this paper, we address a specific type of crowdsourcing, which uses human intelligence and collective processes to support scientific enquiry (Von Ahn 2009; Gregg 2010).

This form of scientific enquiry on the Web is commonly referred to as citizen science (Bonney et al. 2009). It relies on a crowd of volunteers to carry out well-defined tasks that require little professional training or context.[1] In citizen science, a scientific problem is broken down into smaller pieces (microtasks), which can be addressed independently from each other by multiple contributors in the same time. Results from the crowd are validated and consolidated and feed back into scientific experiments. Projects now exist in many scientific fields, from astronomy to zoology, and the related microtasks are just as diverse: from identifying cancerous cells in human tissues by recognising specific types of objects in pathology images, to studying what species live in national parks by scrutinising live feeds from relevant locations.

While the diversity in applications shows just how important the support from citizen scientists has become in modern science (Waldrop 2008), success is not guaranteed (Tinati et al. 2015b). Designing a successful citizen science project raises socially and technically tough questions: how can a fairly complex scientific problem be translated into microtasks that people can carry out on their own without substantial training? What motivates people to take part in such endeavours? How to make the experience more engaging and rewarding for them? What is the role of volunteers and the processes they use in a scientific workflow? These questions – among many others – have inspired a growing body of research in several disciplines, including social computing, online communities, and HCI, including system studies (Raddick et al. 2009; 2010a; Zook et al. 2010; Tinati et al. 2014) and design practice studies (Kraut et al. 2012; Reiss 2004; Preece 2016).

The work presented in this paper focuses on one of the most successful citizen science projects to date, Eyewire[2], which is a Web-based citizen science where players compete to complete puzzles which are computerised images of neurons in the Human brain. Unlike many citizen science projects, Eyewire offers a unique mix of gamification, communication, and scientific workflows.

Our work builds on existing research investigating the social components of citizen science (Mugar et al. 2014; Siu, Zook, and Riedl 2014; Tinati et al. 2015b; Bowser et al. 2013), as well as recent studies of the Eyewire platform (Tinati et al. 2016; 2015a). Given the growing acknowledgement that citizen scientists are not *just* a class of unpaid crowd workers, we wish to examine in more depth how socially-empowering features are used by the players, and how this impacts their overall experience, not just the impact of these features with respects task completion performance. We draw upon participants' responses to an on-

[1]Some authors use the term 'virtual citizen science' or 'online citizen science' to emphasise the use of Web technologies and platforms to achieve results faster and at greater scale than pre-Web citizen science initiatives, which have been around for hundreds of years.

[2]http://www.eyewire.org

line survey, as well as 2-weeks of hand-coded real-time chat messages, and ask questions about the role of real-time chat in supporting crowd contributions and engagement with other members of the community. We aim to develop a richer understanding of citizen science engagement beyond the extensive studies describing the motivations and factors for participation in projects(Raddick et al. 2010b; Reed et al. 2013)

The study informs the ongoing debate around the effective design in citizen science, and to advance previous work on the role of the social in citizen science design (Greenhill et al. 2014; Eveleigh et al. 2013; Tinati et al. 2016) by offering detailed qualitative insights into the role of real-time chat in this context. In summary, real-time chat influences the way people interact with the system and with peers in three main ways: it facilitates (a) collaboration on tasks; (b) peer learning and sharing knowledge with others; and (c) asking for and offering help within the community. We use these findings as a starting point to reflect on how designers could effectively bring together rigorous scientific experiments with crowd-based processes which tend to be less structured or formalised. In addition to helping designers explore system features, we regard our findings useful for two other audiences: for scientists in all subjects, who are considering using citizen science and need to get familiar with their design space; and for researchers in fields such as online communities, CSCW, HCI, crowdsourcing, human computation, and open science, who have identified citizen science as an increasingly important class of online systems that deserves to be studied and better understood.

Related work

There are several strands of research which have inspired this study of the role of discussion in citizen science. We draw upon existing literature pertaining to studies of citizen science platforms; as well as on studies and related frameworks of motivation and participation in online communities, and the study of computer mediated communication (Herring 1999).

Previous studies of citizen science and other crowdsourcing platforms have tried to understand what drives people to engage in such activities (von Ahn and Dabbish 2008; Raddick et al. 2010a; Zichermann and Cunningham 2011; Bowser, Hansen, and Preece 2013; Iacovides et al. 2013; Rotman et al. 2012). Brabham *et al.* 2008 found that contributors were motivated by both the ability to be creative in a social way, while making money and improving their reputation and skills. Moor and Serva 2007 articulated motivations based on correlating expressions, identifying different categories of motivations, which cover intrinsic and extrinsic aspects. This has contributed to the ongoing investigation and debate around reward vs. intrinsic factors of participation (Raddick et al. 2010a; Jackson et al. 2015; Tinati et al. 2014; Baruch, May, and Yu 2016); with the latest findings arguing that it is rather the latter (such as altruism, collaboration, and personal interest) that drives the participation of amateur scientists. Their findings suggest that whilst extrinsic factors (such as competition or reputation) might work well to attract initial interest, it is the intrinsic desire to contribute to a worthwhile scientific cause that becomes critical for sustained participation and community engagement.

Although the social component in Web-based citizen science is fairly new, the use of computer mediated communications (CMC) is well-documented as an approach to help users learn, socialise, and gain support (Herring 1999; Nardi, Ly, and Harris 2007; Berns, Gonzalez-Pardo, and Camacho 2013). CMC has primarily examined platforms where learning is the primary focus, e.g. teaching environments, distant learning, etc. With respect to citizen science communications, and more specifically Eyewire, CMC has studied both asynchronous and synchronous forms of communication (e.g. forums vs real-time messaging), and its affect of learning and socialising (Chou 2001; Johnson 2006; 2012). Findings from these studies suggest that both forms of communication have a role in learning, and depending on the environment (e.g. teacher-student, peer-to-peer), real-time communications can be favourable. However, in contrast to platforms where the primary task is for learning (e.g. a distant learning platform), in citizen science where the primary task is to crowdsource work amongst volunteers, the inclusion of social communications may lead to unexpected outcomes, with respect to the user experience, and the tasks being completed, as early citizen science studies discovered (Luczak-Rösch et al. 2014).

However, whilst there is growing evidence of the opportunity of using social features in citizen science to increase public awareness (Tinati et al. 2015a; 2016; Mugar et al. 2014; Crowston, Prestopnik, and Wang Submitted; Preece 2016), engagement with the community about collaborative modes of scientific enquiry is less well documented, with only recent studies beginning to explore the value in co-produced knowledge (Pandey et al. 2017). This shifts away from the current paradigm of the crowd worker, to considering how individuals can make a significant impact (individually and collaboratively) on the advancement of scientific knowledge. This is being addressed by combining out understanding of citizen scientist 'motivations', along with the type of workflows that citizen scientists develop alongside the highly prescribed workflows for task completion.

In our research we analyse the communication of Eyewire players through the same lens that we would use to understand interactions in a online community. We extend recent work which has looked into the usage of chat for facilitating competition and game interaction (Tinati et al. 2015a). We carry out a qualitative analysis of how participants in Eyewire conversations report their use of the chat, in combination with a hand-coded analysis of how they converse and interact.

Research Question

The study is framed by the question of how players use Eyewire's real-time chat interface; it focuses on the *interface* and *sociality* design features pertinent to improving the overall user experience of a citizen science system.

Eyewire

Data and Methods

Survey data. Eyewire players were asked the following question: "How do you use the real-time chat console"? This was part of a self-administered online survey run in September 2015 . The survey invitation was shared with all members of Eyewire via an email newsletter. In total 1, 365 responses were received.

Real-time chat data. In addition to the survey data, we obtained 53, 090 chat messages from the real-time chat console in Eyewire in order to learn more about the interactions among participants. These were all chat messages produced during a randomly selected two-week period in February 2015. The messages also included a number of system-generated bot messages and status updates about users (e.g., performance or joining notifications), and players issuing game commands (e.g.,'/stats' can be used to see how well a player is performing). Whilst it was possible to remove these messages prior to the coding, we agreed to keep them to ensure that any conversations were identified without filtering, as this may affect the flow of a conversation – for example, a single conversation might appear as two if a series of auto generated messages were removed, which occurred during a single conversation.

Methods and Coding Based on methods used in existing studies of social communication (Paulus, Warren, and Lester 2016), we conducted qualitative coding to identify themes within the chat messages and survey responses (Pope, Ziebland, and Mays 2000). Two researchers were given a 10% random sample of the responses to code. Each of them generated their own codes based the activities described by the participants (no themes or codes were given to begin with). Once completing the initial 10% sample, researchers agreed on a set of final codes which represented the motivations found, without containing replication. In order to validate the coding performed between researchers, we used Cohen's Kappa coefficient as an inter-coder reliability measure, and calculated an agreement of 85% between codes.

We used a similar approach to code the chat messages. Researchers were given initially given half of the chat messages each, and asked to identify conversations between players. They were asked to mark when a conversation started and ended, which chat messages they deemed not relevant, and which players were not contributing to a conversation. The marked conversations were then checked by the corresponding researcher, and agreement was reached. Again, we found an inter-coder agreement (Cohen's Kappa) of 80% between researchers. Following this, coding of the conversations was performed, with the agreed coding schema shown in Table 2. Tables 1 and 2 provide an overview of the final codes. Response and conversations may be related to multiple codes, for example, a response may be associated with 'Gaming', as well 'Science'.

Codes	Sub-code	Description of code
Help		***Responses describing their use of chat for asking for help***
	Game	*Asking game components questions, e.g. scoring*
	Task	*Asking task components question, e.g. rotating the cube*
	General	*Asking Eyewire platform questions, e.g. log-in issues*
Learning		***Responses describing their use of chat to learn***
	Scientific	*Asking about the science of the game, e.g. How are the puzzle images produced*
	General	*Asking about the Eyewire platform, e.g. How to complete puzzles efficiently*
Social		***Responses describing their use of chat to socialise***
	Observation	*Lurking behaviour, without contributing to the chat*
	Participation	*To participate in general conversations*
	Sharing	*To share with others their current progress and ways of working*
	Celebrating	*To celebrate either their own success, or congratulate others.*
Gaming		***Responses describing their use of chat for gaming purposes***
	Competing	*To compete with others, e.g. set a challenge*
	Team play	*To communicate with others within a team*

Table 1: Coding schema of Eyewire player responses to the question "How do you use the real-time chat console".

Codes	Sub-code	Description of code
Help		***Conversations about their use of chat for asking for help***
	Interface	*Asking for help about the user interface, e.g. how to rotate cube*
	Task	*Asking for task help, e.g. Can someone take a look at Cube XX*
	Game	*Asking for game related help, e.g. How do I get more points*
	General / Unrelated	*Asking for general help e.g. How do I organise my time more efficiently?*
Processes		***Conversations about their use of chat for taking about processes***
	Task	*Discussing task processes, e.g. I've just started cube XX and I've noticed...*
	Team	*Discussing team processes, e.g. player_name, are you working on cube XX, I'm…*
	Gaming	*Discussing game processes, e.g. I've just had a trailblazing streak, what's the best...*
Knowledge		***Conversations about their use of chat for either asking or sharing information***
	Sharing insight	*Discussions about platform insights, e.g. Clicking X will allow you to...*
	General science	*Discussions about general scientific discovery, e.g. Did you hear about the new study which...*
	Neuroscience	*Discussions about neuroscience and Eyewire findings*

Table 2: Coding schema for 2-weeks of EyeWire chat messages

Results and Analysis

To begin with, this section summarises the coding performed. In total, 1, 365 responses, and 2, 000 conversations were manually coded. From those 2, 000 conversations, 73% of the total corpus of messages were included. 80% of the conversations contained between three and five players; they ranged from short bursts of discussions (typically less than five minutes) to longer drawn out discussions (up to two hours). The longer conversations were identified as conversations asking for help, or requesting information about a specific task. 63% of all players in the corpus were identified in one or more conversations.

We identified three cross-cutting themes, which reflect the results of the coding from the survey responses and chat messages: (a) collaboration and discussion around joint tasks; (b) learning and sharing knowledge with others; and (c) the opportunity to help or receive help and advice.

Help and Support. A cross-examination of the player's responses and chat messages revealed that there was a tendency to use chat for obtaining help, learning, gaming, and socialising. We identified two types of responses relevant to *helping*: those who were helping other members of the community; and those who were either explicitly asking for help or were browsing the chat log in order to identify content that might answer their questions. Below are an example of the responses from players offering or asking for help:

"Helping others! communicating with advance players and building a lasting community.",

"When newcommers require help and advice, I like to make sure they're doing ok"

"Mostly to ask for help. There are some very experienced players, which can solve problems very fast. Sometimes I think, they have knowledge more than other (I dont speak about admins)."

Based on the conversations analysis, several reoccurring players were identified within many different conversations offering other players support and troubleshooting. These players appeared to remain active on the chat console waiting to contribute their expertise and offer support to those who might require it. Due to the real-time nature of the communications, the responses by the community, and the 'expert' users were quick to respond, which allowed a natural form of conversation to emerge between the notice and experienced players. In contrast to this, other citizen science platforms offer forum-based communications, which are asynchronous in nature, thus potentially limiting the potential for responsive conversation. Below is an example of a typical conversation asking for help.

Player A i need help

Player B we can help

Player C yep, half of my job is helping players

Player A ok i need to know a little about the control?

Player C ok, are you in the tutorial still?

Player A umm in the practice cubes, so no

Player D Click on the gear at the lower right part of the screen to see available controls.

Player C ok practice cubes—-which controls are you having issues with, all of em?

Player A yeah exept scroll erase and draw

Player C ok, so click on the ? it has all the commands

...

The coding also revealed many conversations focusing on processes within the Eyewire platform: how does a task work, how can one take part in teams and competitions, how does a particular game element work, and so on. What distinguishes these conversations from those labelled as 'Help' was the nature and context of the discussion between players. There was no specific question being asked, but rather an exchange of messages which discussed how Eyewire works, what different features are available, how they can be used, etc. These conversations were on average twice as long in duration as the help-related ones, and contained on average more than 50% more players. Conversations also extended to citizen scientists discussing topics related to the gamification elements (e.g., the race to the top of the leaderboard), or team discussions, such as the tasks that a team should be working on. We noticed that these threads exhibited a less linear narrative – players would all be contributing to the discussion, sharing their views or their current state of play.

Player A: Okay, I need to ask this. Any tips on becoming a scout?

Player B: wait for the next hunt/challenge/other way they will promote players

Player C: get good at finding mergers

Player B: and be active in the mean while

Player C: hunt! theres one soon

Player B: that too

Drawing upon existing studies of crowdsourcing platforms, providing community-driven advice, support, and expert feedback is a critical component of a successful community (Tinati et al. 2015b; Curtis 2015; Burgers et al. 2015). The analysis of the chat corpus and survey responses indicate that the chat has several help and support functions, enabling players to discuss problems during their task sessions, and seek further assistance regarding specific tasks they are working on. In several instances, players were able to request the help of more experienced players to take a look at their current progress on an task, as they were unable to proceed without advice. Another factor for successful citizen science concerns the onboarding of new users, and supporting their initial activities (Jackson et al. 2015).

Learning. We found a class of responses pertaining to the use of chat as a means to learn more about how the EyeWire game works, and more specifically, about Eyewire's contribution to science. Responses to the survey suggest that players are actively sharing knowledge and information, and also asking others for detailed information in order to learn about specific areas of interest. Several responses described their experience as a great chance to learn in an *"informal"* and *"personal environment"*. For instance, the responses below describe how the interactions with other players offers a great chance to learn in a collaborative environment:

"I've always been interested in science, and this is a great chance to develop this, with others like me".

"Advance players really have a good understanding of how the tasks work, they're always willing to teach and show us".

Conversations labelled under the learning code were typically associated with discussing the science of Eyewire. Within this set of discussions, we were able to identify subthemes where players were sharing insights which they had found, which then spurred on others to ask more questions and learn more. For instance, we found conversations initiated by players who were sharing their knowledge of specific tasks (the 'cubes'), without any prompting. In other scenarios, such as the conversation below, a detailed discussion, forms around a general scientific question:

Player A: are the memory cells a part of the eye? i thought memory cells are only in brain

Player B: But it has a very good connection with it.

Player C: [the eye] transmits these signals [image s] to the brain through complex neural pathways that connect the eye via the optic nerve to the visual cortex and other areas of the brain.

Player C: So I think it is pretty safe to assume that what you may have found is, in fact, an eyeball

Player A: ya it sends to many parts of your brain, is it why some blind people can still avoid objects or reconize faces, without noticing

Player A: also that is they reason we get deja vu

Player C: Thats how dejavus happen too

Player C: exactly sgt pepper

Player A: ya its cool, there is a useful vsuase video talking about it :P

Player C: the brain stores the images in the memory part and only then do we analyse them, thus creating the idea that it has happened before, I got here through VSauce too!

In previous research, studies have explored the role of multi-channel interactions (e.g., community discussion in combination with completing tasks) as a means to learn and improve a participant's knowledge (Luczak-Rösch et al. 2014; Rotman et al. 2012; Mugar et al. 2014; Culbertson et al. 2016). In other citizen science platforms, forums facilitate a spectrum of questions: from interface and task design to possible scientific advancements. Similar to other platforms, we found that in Eyewire, players are able to use chat for a variety of learning purposes, in particular as a collaborative, real-time experience. Although we cannot determine whether players seeking to improve their skills by asking for help in the chat do actually improve their task performance, the responses resonate with other studies which have established such links more clearly in other citizen science contexts. As described in (Bonney et al. 2009; Luczak-Rösch et al. 2014; Masters et al. 2016), the most prolific contributors in terms of tasks completed and community activity are those who develop their own domain-specific expertise and task skills. This is reflected by Culbertson *et al.* 2016 and Master et al. 2016, who suggest that engagement in community features can support learning, which can facilitate more general scientific knowledge.

Responses also revealed another aspect to chat. Participants do not necessarily need to contribute to the conversations to benefit from the ongoing discussions. The coding showed that several players used the chat console as a tool to observe other players activities and that the back-channel discussions had benefited their own experience. This behaviour draws parallels with existing studies (Nonnecke and Preece 2001), where *lurking* was identified as being just as important as direct engagement. Below are a selection of relevant answers from the survey:

"Even though I tend not to participate in chat myself, the discussions that I see go by have great tips and observations that I wouldn't have been able to figure out on my own."

"I am mostly just interested in reading the comments of others without too much participation on my part."

As a methodological note, this *lurking* behaviour highlights how interface components such as chat can being used in ways which are not captured by system logs, thus their true value to a population might only be exposed with such exploratory methods (e.g., surveys, interviews).

Collaboration and Socialising. Survey responses described how players use the chat function in order to contribute to a project more effectively. Players describe their use of the team coordination capabilities to discuss and solve difficult tasks that require multiple inputs, despite not being able to see historical chat messages, or view multiple threads within the chat interface. For instance, the examples below illustrate types of responses coded as observations, participating, celebrating, and sharing information with their fellow players:

'listening to others",

"congratulate others"

"initiating team activities for increasing productivity"

"raising awareness of current activities and progress of Eyewire"

Process-driven conversations form the ongoing back-channel of discussion that fuels the chat console. The longer conversations identified tended to discuss task related activities, and over time, attracted the participation of many players, contributing sporadically throughout the day with useful contributions to a discussion, or make some announcement about achievements or tasks requiring assistance. These discussions also include more collaborative interactions, through the use of team and gaming features. In comparison to other citizen science platforms such as the Zooniverse (Luczak-Rösch et al. 2014) which use discussion boards and forums for social communication, we were interested to see conversations which spanned several hours (with some even spanning from evening-till-morning). As the real-time chat does not contain a historic log of messages (i.e. when a player logs on, the chat console has no existing chat messages), this suggests that for these lengthy conversations, players remain active on the platform for many hours. One could question whether the behaviour of these players is a sign of a strong community, given that many of the lengthy conversations were support or task related. As players are not scored on their contributions to chat (they are scored on how well they complete a task), these social interactions illustrate the intrinsic motivations of the players.

Responses describe how the chat interface facilitate various aspects commonly associated with online communities (Zhang, Ackerman, and Adamic 2007), sharing experiences, self-regulation, and forming friends (and teams). Unintentionally, the chat console has emerged as a feature of dual purposes. It has been used to discuss the scoring, success and teamwork between players, and to offer an environment to help newcomers, provide advice, and support players who wish to learn more about the science underpinning Eyewire. The following examples illustrate this:

"talking to other players, some of who are good friends"

"It's just a good place for some chatter between games and with friends"

"There's always the regulars on there, it' fun to listen and take part in the chatter"

In the context of the broader citizen science literature, establishing an active self-organised community of volunteers is essential for running a successful, long-lasting citizen science project (Zook et al. 2010; Nov, Arazy, and Anderson 2011; Tinati et al. 2015b). In Eyewire, our findings suggest that alongside the unique design and functionality of Eyewire as a game, the real-time chat console has helped establish and facilitate a true Eyewire community. It has enabled interaction and collaboration in an environment that does not feature an explicit social layer - that is, there is no explicit mechanism to friend other players, follow them etc. Our findings, similar to studies such as (Culbertson et al. 2016; Greenhill et al. 2016), have shown that the chat interface provides players with the ability to engage with others interested in similar topics and points of discussion (Tinati et al. 2016).

Design Recommendations for Citizen Science

Based on the analysis of the survey responses and chat messages, and drawing on studies concerned with the design of online communities and crowdsourcing platforms (e.g. (Gregg 2010; Jennett and Cox 2014; Eveleigh et al. 2014; Kraut et al. 2012)), we consider several social and technical design features (summarised in Table 3 which can be used to improve the experience of users, and in turn improve the performance of a citizen science platform. Whilst we base these design considerations on the analysis of the Eyewire citizen science game, as increasingly there is growing consensus towards what motivations citizen scientists, our findings may have application beyond the Eyewire platform.

Real-time Communication for Effective Work

Citizen scientists working solo alone can be one of the reasons for losing participants (Eveleigh et al. 2014). In Eyewire, communicating with other players, whether for social support or general discussion has been identified as important for user retention. Unlike the majority of citizen science platforms, Eyewire benefits from the real-time functionality of the chat interface, as it allows players to collaborative in a timely fashion. Taking this into consideration, offering features where communication can lead to collaboration (e.g., team play) and can be beneficial for the community and the science team. Collaboration can take different forms: from coming together to carry out work set as a challenge, to discussing and sharing solutions for the same task.

Ongoing discussion leads to scrutiny of the tasks being completed. In Eyewire, we found multiple examples where players request additional eyes on the task they are working on in order to ensure that they are accurately completing their task. However, despite the concerns that collaboration of this kind increases the time take to complete a task (Tinati et al. 2015a), players are more likely to remain engaged for longer. Our analysis supports this; ongoing background conversations contributed positively to the overall experience of the player. To that end, platform designers should consider the complexity of the task and the potential for improving a player's engagement and overall performance, and decide whether peer communication interface such as real-time chat can benefit both the players, and the overall project goals.

A concern for designing human computation and crowdsourcing platforms is the danger of cheating and collusion; which could be promoted via peer communication - this is, for instance, the case in the ESP Game or other multiplayer games with a purpose (von Ahn and Dabbish 2004; Cooper 2013). Allowing users to consult with their peers while solving a puzzle means that quality assurance mechanisms based on redundancy might be less useful - these algorithms work under the assumption that a task is solved independently by multiple players and compare the different solutions to infer the correct one (e.g., by majority voting). However, in Eyewire these effects seem to be minimal, due to the type of task being completed. players cannot edit a puzzle once submitted and have only very generic means to ask questions to the community. Taking this into account, the chances of collusion needs to be considered against the type of citizen science task.

Structured Community Feedback

Support, whether expert- or community-driven, was identified as an essential feature for retaining participants and ensuring newcomers can start contributing as soon as possible (Jackson et al. 2015; Mugar et al. 2014). However, in the majority of citizen science platforms community support has been separated from the task component. In Eyewire, questions or game commands are issued in the chat interface, with no direct connection with the task interface. Similarly, in platforms which use discussion forums, communication is a decoupled process (Luczak-Rösch et al. 2014).

In Eyewire, complex questions are often fielded by the community. During conversations, players often requested the help of specific members, suggesting that the community has recognised that different players are able to answer questions based on the type of knowledge required. Expert players are willing to help, and often discussions include multiple users with extensive knowledge of the platform. This can initially be improved by providing a mechanism to allow one-to-one mentoring or through community moderation (with elevated levels of authority). As the chat console has been shown to be beneficial for providing support for players (with many of the same questions being repeated at different time periods), more structured features can be used to enable different types of questions to be asked, which could be directed towards specific members who are more inclined, or have the expertise to answer.

For a citizen science communication interface, more granular feedback mechanisms (e.g. not just console commands) can be integrated directly into the platform and task interface. For example, by decomposing the task into different stages, each with their own achievements and scores, or by showing players the solutions of their peers. Related literature (Feyisetan et al. 2015) found that this is especially valued among top players who are keen to improve their performance and learn. This is also consistent with our survey results, where learning was identified as a key theme. Taking this into consideration, one could bring peer support closer to the actual game play rather than keeping it in dedicated separate channels. For example, while completing a puzzle, a player could be informed about other citizen scientists who are tackling the same area at the same time. This sense of 'connection' has been shown to increase participation (for instance, in GWAPs (Siu, Zook, and Riedl 2014; Thaler et al. 2011)).

Modes of Operation and Configurability

Traditionally, the default workflow in citizen science has been that users individually complete a task. Only recently,

Recommendation	Benefits	Considerations
Real-time chat interface	Real-time enables timely and responsive feedback	Distraction and slower task completion
Public communication channels	Observing discussions can support user knowledge	New users may be shy to contribute in a public space
Structured Feedback	Improved response rate as questions matched with appropriate users	Users can become reliant on using structured approach and avoid serendipitous findings
Decomposing of Tasks and Communication	Conversation becomes relevant to the users of a specific task	Potential for users to become fragmented into sub-communities
Chat Interface Configuration	Users are able to adjust their interface to correspond to their workflow preferences	Potential onboarding problem as new users may not know what to do.

Table 3: Design recommendations for peer communication and social features in a Citizen Science Platform. Summary of benefits and considerations of their implementation

players are offered the capability to interact with the community via peer communication. Eyewire has experimented with richer features for collaborative work as alternative workflows and roles of contributors. These are still informal and are not explicitly documented within the platform; it is the task of players to seek this out from other sources (e.g. listening to other players in the chat console). Despite this, using Eyewire's teamplay and other collaborative modes of operation, players are able to coordinate tasks and work, from basic modes of operation such as asking others to examine a specific task they are working on, to more complex modes of operations such as dividing up tasks between players based on experience. However, currently these workflows are socially-driven, and not officially part of the platform. True 'citizen science' collaboration and team play could mean that different players would be able to contribute to a single task in different ways. For example, one could imagine that one member of a team validates the solutions of others or that players take turns in solving a puzzle. Experience, interests, and skill sets could all contribute to the roles of players within the teams, and this could be reflected in the type of rewards given. Finally one could also experiment with different multi-player modes such as input and output agreements (Oluwaseyi and Simperl 2016).

Enabling participants to configure their chat interface and their level of community engagement has shown to be effective in increasing a player's performance; for instance, providing players with the option to silence and focus on their own task when they desire (Tinati et al. 2015a). As responses described, Eyewire's interface allows users to engage with certain features, including interacting or silencing the community when undisturbed sessions are required. This flexibility was shown to be important, and can be further improved by allowing the community to design their macro's, interface tools, and layouts. In several cases, we observed players using a combination of commands within conversations to notify or look up another player's status. Similar to the community-led support mechanisms and modes of learning, players could be given more scope develop and integrate their own scripts, commands etc.

Limitations

There are several limitations pertaining to the data and methods used in this study. First, we recognise that the responses to the survey, and the players included in the chat messages, represented only a subset of the total population of active Eyewire members. While one could claim that this is a well-known challenge in a majority of surveys and questionnaires (Savage and Burrows 2007), we believe that using a qualitative approach exposes the nuances of why and how people engage. Participant responses present a much richer view of a socio-technical system, such as Eyewire. Second, we appreciate that what people say they do, and what they actually do are often disjointed. We hoped that the use of coding the chat data would help us close this gap. However, in doing so, we are aware that by selecting a 2-week period of messages is in itself, problematic. In reflection, one could sample daily logs of chat messages, rather than take a single block of time. This might reflect the discussions of a wider pool of players. However, this approach also risks the possibility of missing sections from a conversation, depending where the start and end of the sample is taken. Finally, we recognise the problem with using only a selected number of researchers to code and interpret the data. Whilst we cross-validated the coding results, the reliability (and possible diversity) of codes and themes might have been different with more (or other) researchers.

Conclusion

In this paper we studied computer-supported peer communications in the citizen science project, Eyewire, and based on our findings of how players describe their interactions with the platform, and how thy form conversations within the real-time chat interface, we developed a set of design recommendations for similar citizen science platforms.

Our findings reveal that players engage with the real-time chat for several performance, support, and learning activities. We found evidence for players establishing new forms of collaborative uses, despite there being no formal features for such activities within the chat interface. Players described how they supported other members in the community, onboarding newcomers, asking and answering questions, learning and sharing insights, as well as casual discussion and collaboration. Our findings reinforce the importance of real-time peer communication in order to greatly improved players' social engagement, and thus, engagement in the citizen science project. Eyewire players have been able to establish a community without an explicit community model present; experienced players support newcomers; and players are known by the community, to the extent where detailed and lengthy conversations can form and they request certain other members to join and contribute.

The chat function, along with a supportive community, has also helped facilitate an environment where players can learn the science behind Eyewire, partly with the help of their peers. However, beyond providing an enjoyable environment for people to interact and possibly learn, Eyewire has successfully managed to attract and retain players, and complete many milestones in their scientific endeavours. By synthesising these findings, we have described a set of design recommendations which can be used to guide the implementation and configuration of real-time communication interfaces within citizen science platforms.

Our future work aims to extend the current investigate and classify what type of expertise and knowledge is obtained by contributing to citizen science activities, and to what extend this expertise is transferable to other domains and platforms. We plan to study in more depth the types of questions asked by players via the chat and the effects of learning. Using this insight, we wish to investigate the structured capabilities around peer-support and feedback which real-time citizen science chat can offer. We also see great opportunity to improve the current workflows; experiments are required to determine if modifying solo workflows impacts the validity of contributions, which would address recent concerns with cheating and collusion in microtask based platforms (Pre 2014; Gadiraju, Kawase, and Dietze 2014).

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