# '/Command' and Conquer: Analysing Discussion in a Citizen Science Game


## ABSTRACT

Citizen science is changing the process of scientific knowledge discovery. Successful projects rely on an active and able collection of volunteers. In order to attract, and sustain citizen scientists, designers are faced with the task of transforming complex scientific tasks into something accessible, interesting, and hopefully, engaging. In this paper, we examine the citizen science game EyeWire. Our analysis draws up a dataset of over 4,000,000 completed game and 885,000 chat entries, made by over 90,000 players. The analysis provides a detailed understanding of how features of the system facilitate player interaction and communication alongside completing the gamified scientific task. Based on the analysis we describe a set of behavioural characteristics which identify different types of players within the EyeWire platform.



## Keywords

Citizen Science; Gamification; Player Behaviour; Online Communities

## Categories and Subject Descriptors

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


## 1. INTRODUCTION

Web-based citizen science has become of a recognised and successful application of crowdsourcing to solve computationally intensive problems. The use of crowdsourcing techniques for citizen science has shifted the emphasis from machine-driven (see [3]) to human-computational approaches.

The primary task of a citizen science system is to present scientifically complex tasks in small, accessible workflows that can be completed by non-expert volunteers. The use of crowdsourcing techniques for citizen science has shifted the emphasis from machine-driven (see [3]) to human-computational approaches. Citizen scientists are now offered an interactive environment that goes beyond problem solving. Some citizen science platforms provide users with communication mechanism, which in some cases have led to collaboratively discovered scientific knowledge [10, 26].

Successful citizen science platforms are able to mobilise thousands, if not millions of volunteers to work together. Understanding the behaviour of humans using systems on the Web is generally important for achieving sustained engagement and participation[1, 36]. The time-critical nature of some citizen science projects (e.g. Cell Slider[1]) emphasises this. Achieving the necessary level of participation can be the key to identify - and potentially cure - a disease or to make a scientific discovery.

There are various models to describe the growth, uptake, and decline of online communities, such as social networks or peer-production systems [34, 17, 14]. Often the focus is on devising metrics to interpret and predict participant's activities. However, as a recent study of a multi-domain citizen science platforms has shown [27], the interaction with a project and the behaviour of citizen scientists is often unique. This impacts which analytical methods can be applied to understand system-level behaviour. In this paper we contribute to this line of work by providing a system-level analysis of EyeWire. The purpose of this study is to describe the characteristics of user interaction in order to set the agenda for further research on the EyeWire system.

EyeWire is a citizen science project that mobilises volunteers to mark neurons of the human brain in 3D-rendered functional magnetic resonance images (fMRI). Completed games are rewarded by points, leaderboards and individual player statistics help with keeping track of one's progress and comparing with others, and competitions let players challenge each other in teams. In-line with existing studies of online citizen science [27], this study provides insight into the functionality and characteristics of such a system with particular interest in the relationship between participant's communication and their task activity. The study uses a dataset of player activity in EyeWire[2]. We ask three questions regarding player participation in relation to features of communication and interaction: (1) What is the relationship between real-time chat and the gaming process? (2) What do players use real-time chat for? (3) Does real-time chat facilitate discourse and collaboration between players?

*Summary of Contributions* The study presented in this paper is the first system-level analysis of player behaviour in EyeWire. Our findings describe a set of player characteristics that help distinguish highly active players based on their interaction with EyeWire's built in real-time chat system. EyeWire players who participated in real-time chat remain active for longer, and completed more games during the lifetime of their account. Furthermore, we found that highly active players could be identified by how real-time chat was used

[1]Cell Slider **http://www.cellslider.org** is a project to identify cancerous cells
[2]as of 5th August 2014

during the gaming process (e.g. does a player chat before or after a game), and also by their use of game commands in the chat interface. Based upon these findings we describe a set of features which can be used to distinguish active players in a citizen science game.

The remaining sections of this paper will be as follows, Section will describe related work with regards to citizen science, gamification and user retention in online communities. Section will describe the EyeWire platform, describes the methods and data used within the analysis of the EyeWire platform. We then present the results of the analysis in Section followed by a discussion of the findings in Section and and reflect on the questions posed above.

## 2. RELATED WORK

In this section we discuss related work with respects to citizen science, gamification and also studies which develop methods to analyse user interaction, retention and churn.

### 2.1 Citizen Science

Online citizen science originally referred to the idea of using spare computational resources in a distributed network to perform computations at scale as part of scientific experiments [3]. The rise of Web 2.0 technologies and the associated culture of participation and mass collaboration, has led to a shift away from machine-driven processing towards crowdsourcing, with more projects involving large numbers of volunteers in solving problems that are difficult to tackle using state-of-the-art automatic algorithmic techniques [12, 23]. Studies have analysed the fledgling communities of amateur scientists, examining the main drivers for user engagement [23, 29], the effect of social features such as discussion forums on user behavior [27], and the emergence of citizen-led scientific discoveries alongside the original scope of contributions defined by the science team [9].In line with this human-computation [35] angle on crowdsourced science, current citizen science research explores aspects such as the performance of contributors in terms of task design and completion, with the aim to improve accuracy and efficiency [11, 21].

#### *2.1.1 Citizen Science Games*

The use of game design elements (or gamification) is commonly used by designers to engage individuals in non-gaming contexts [15]. It has been applied to many domains, from devising new teamwork strategies in enterprises [30] to developing successful means to support crowdsourcing tasks [4], and is typically associated to artefacts such as point systems, achievement badges, progress bars, leader boards, and challenges which strive to leverage people's intrinsic and extrinsic motivations [28, 32]. Systems developed under the label 'games with a purpose' (GWAP) [35] exploit similar ideas, but disguise the problems to be solved behind an actual game; players interact with the game, and the results of this interaction input into solutions to the original problem.

This design paradigm has found many adopters in citizen science, including projects such as FoldIt [23], EteRNA[3], Qunatum Moves[4], ARTigo[5], Phylo [21], and EyeWire, which is the subject of the research presented in this paper. Common to these systems is the fact that they offer a game interface for citizen scientists to contribute to the basic task, as well as various other means for them to interact (and compete) with their peers. Whilst still being a young area of research, first studies have already started to analyse challenges and design considerations of building citizen science GWAPs [7].

[3]**http://eterna.cmu.edu/web/**

[4]**http://www.scienceathome.org/**

[5]**https://www.artigo.org/about.html**

### 2.2 User Churn and Retention

Modelling the retention of players has increasingly become an important area of research, with studies ranging from online forums [13] to question answer systems [1], to peer-production systems [25], social recommendation sites [14], and social networking sites [34]. Studies of user engagement also expand beyond Web systems such as Richter et al. [31] study of customer churn in telecommunication markets. Most prevalent in this field of research is the use of social and behavioural modelling in order to understand and predict the churn of players over a period of time. A range of machine learning techniques are typically used to model and examine which features of a user's interactions can best describe and predict their retention and likelihood of returning. Common approaches include using inherent system functionality as a means to identify different user groups, Burke et al. [8] examined and classified players by their sharing behaviour. Similarly, Dror et al. [16] explored user behaviour on the question answer service, Yahoo! Answers. Results indicate that measuring the engagement of players by their their comment ratings use provides a suitable means to identify returning players. Borbora [6] examined user retention in a social gaming platform, comparing two groups of players, regular players (those that return) against those that stop. Identifying the characteristics between these players a distance metric was identified which could help predict players who would not return.

## 3. EYEWIRE

EyeWire is a citizen science project that enlists volunteers - known as *players* - to mark neurons of the human brain in 3D-rendered functional magnetic resonance images (fMRI). Although this is a computationally possible task, the time required and level of accuracy that even the most advanced visual identification algorithms is far less efficient than possible by crowdsourcing techniques. As of present, the project has over $130,000$ participants from 130 countries. Crowd contributions are combined with state-of-the-art AI intelligence algorithms to create a detailed map of the connections of neurons - the so-called 'connectomes' - at the back of the human eye, hence helping neuroscientists to gain a better understanding of the ways we process visual information. As EyeWire does not specify any formal training, players represent a vast demographic of age, education, and occupation [6].

Figure 1 illustrates EyeWire's interface and functionality. The central region marking task is performed by clicking with the cursor on the 2D visualisation on the right in an area that is suspected to be part of the current neuron. The 2D visualisation represents the currently selected layer from the 3D cube shown on the left, which can be rotated for easier inspection. Layers of the fMRI cube can be switched by using the up and down keys.

Players interact with the system via a game interface which invites them to manipulate (span, rotate, zoom) colorful 3D maps to highlight regions with specific physical properties. Completed tasks are rewards by points; leader boards and individual player statistics help with keeping track of one's progress and comparing with others. As Kim et al. [24] describes, by assigning the same task to multiple players, players are competing against each other to colour the same region of a *cube* as another player, which simultaneously trains the accuracy of the EyeWire algorithm. However, in order to reconstruct an entire neuron, thousands of cubes require colouring, which is coordinated by an inbuilt spawner, based on the

[6]Demographic information was collected as part of a internal survey conducted in 2013

consensus achieved during past classifications.

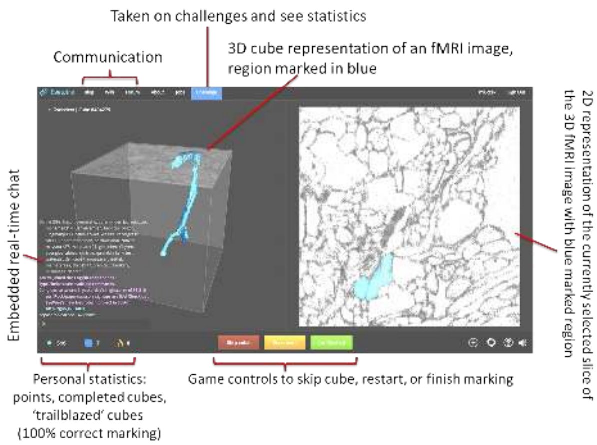


**Figure 1: Main Interface in EyeWire**

Player communications and gamification techniques are integral to the design of the EyeWire platform. As shown in 2, EyeWire contains an embedded real-time chat that allows players to talk to each other, view other players points and achievements, as well as use a number of game commands which provide additional functionality during gaming and talking. Game commands are issued by using a forward slash ('/'), such as being able to mute and hide the chat interface by using the '/silence' command. Issuing player statistic commands are not shown on the public chat feed, unless a player issues a command such as group message ('/gm'), which posts their message to a particular team, in which they first have to join using the '/team' command.

The formation of a team is an community-driven process which usually is a result of an ongoing competition between teams of players. Competitions are either setup by the EyeWire team (usually to encourage or refresh system activity), or led by the players who wish to compete for a specific goal or set of 'badges'.

In addition to the internal chat, the main interface links to additional communication interfaces which are not part of the game. There is the EyeWire project blog, where the community managers promote game highlights, competitions, and challenges as well as new or notably successful players. The players can also consult the EyeWire wiki which contains information about how to play the game, and about the science behind 'connectome' mapping. In addition to this, players are provided with a forum that is meant to be used for more comprehensive, asynchronous discussion on various topics around the game, including error reports.

# 4. DATA AND METHODS

## 4.1 Methods

The analysis of the EyeWire platform involves a study of the system-level properties and the analysis of players' gaming and real-time chat activity. In order to achieve this we developed a model that represents games and chat messages of a player, and extracted a number of features related to their activity. This is then used to examine system-level activity, and cross-player interaction and communication.

In order to examine the activity of EyeWire, similar to previous studies of citizen science project analysis [27], we use player churn and cohort analysis [19] which involves using time window sampling techniques in order to examine the churn of players within a given time frame. The cohort analysis examines monthly cohorts of players based on their first chat and game entry, and provides a measure of sustained activity. Based on the the monthly player retention values, we are able to differentiate between different sets of users, as described in the following section.

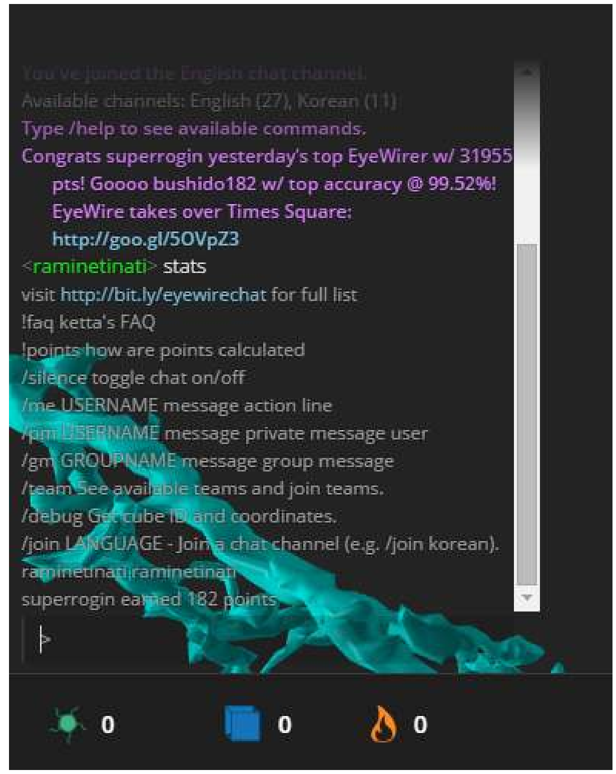


**Figure 2: Embedded Chat Interface in EyeWire**

To examine the context and discourse within the chat messages, we perform text analysis to extract the use of EyeWire game commands, and also perform topic modelling on the content of the chat messages. To achieve this we use LDA [5] to derive topic models which contain common vocabulary used by players. We combine this with the different categories of chat messages in order to determine the context of chat during different stages of completing a game.

As we are interested in the relationship between a players gaming session and use of chat, we construct a model of player chat messages which classify chat activity at different stages of when a game is being performed. As described in Table 1 and illustrated in Figure 3, we categorise the chat messages into 5 stages around the process of gaming. Stages Q1 to Q4 are relative to the time it took for the game to be completed. For example, if a game was completed in 10 seconds, then Q1 would represent 0-2 seconds, Q2-3 represents 3-7 seconds, and Q4 represents 8-10 seconds. In addition to the three stages during a game time window, we also consider 30 seconds either side of the gaming time window (Q0 and Q5). We chose 30 seconds as the lower and upper boundary. 30 seconds was calculated as a suitable duration based upon measuring the distribution of chat messages that fell outside the time window of a game, and using the value of 1 standard deviation away from the mean.

## 4.2 Data

The analysis performed uses EyeWire game and chat data, which

| Stage | Criteria |
|---|---|
| Before Game (Q0) | 30s < Game Start |
| Start of Game (Q1) | Game Start < x < 1st Quartile Game Duration |
| During Game (Q2-3) | Quartile Game Duration < x < 3rd Quartile Game Duration |
| End of Game (Q4) | 3rd Quartile Game Duration < x < Game End |
| After Game (Q5) | 30s < Game End |

**Table 1: Chat Message Stages: Boundary Conditions**

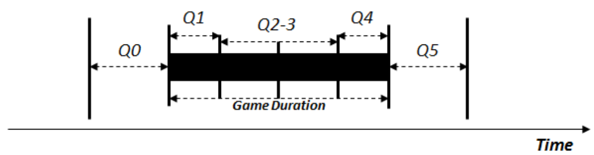


**Figure 3: Five stages of chat messages during the gaming process**

represents player activity between 2012-01-19 to 2014-08-05. The data contains 4,409,998 game entries and 835,732 chat messages, made by 98,224 unique players. For each game, the EyeWire system records the total duration taken (in seconds) for a player to complete a task, and the time the game was completed. Each chat message contains the player's ID, timestamp, and message text.

In order to examine the question of player chat engagement and to offer a finer level of granularity of players with similar characteristics, we extracted different sets of players related to their gaming and chatting behaviour. We initially reduced the data to include players who contributed to both games and chat. we labelled these the 'active' players. Based on these players, we computed several additional sub-sets of players related to specific EyeWire features; for each of these sub-sets we computed a number of statistics and aggregate counts, as described in Table 2.

In addition to computing statistics for the 10,714 'active' players that participated in games and chat, we extracted the top quadrant of 'active' players, similar to the approach taken in other citizen science studies of community engagement [27]. We label these players as 'highly active'. Based on a initial analysis of user retention, 'highly active' players contain individuals who sustained a minimum duration of 30 days with respects to writing chat messages and completing a game.

# 5. RESULTS

The results are organised as follows, we begin by presenting the general findings from the system-level analysis, then explore the role of chat and its relationship with a players' gaming participation. We then report on the chat messages corresponding to different stages of the gaming process, the impact on game commands on gaming, and finally, examine the context of the chat messages by using topic modelling.

## 5.1 General Findings

The general analysis examined the structure and characteristics of the EyeWire platform. We divide this section up by exploring interaction between real-time chat and gaming. As Figure 4 illustrates, there is a long tail distribution of chat and gaming activity. 86.2% of games and 95.6% of chat messages are performed by 10.9% of EyeWire players. These 'active' players engage in both chat and gaming. We note that in comparison to non-gamified citizen science platforms the proportion of 'active' EyeWire players are significantly lower [27], however, EyeWire exhibits a similar distribution of player contributions.

By extracting the the 'highly active' players (defined by those that are active on their account for for over 30 consecutive days), then as Table 2 shows, just over 1% of EyeWire players were responsible for over 50% of the total games ( 2 million).

Comparing players that only participated in gaming (which accounted for 88% of EyeWire players) to those that engaged in both chat and gaming (the 'active' players), we found that the average number of games completed by gaming only players was significantly lower (15 games compared to 255). In addition to this, the overall account length (the total time they were active on EyeWire) of 'active' players was nearly 4 times longer. However, with respects to the frequency to which they completed a game (the delta in minutes between games) those that only participated in the game spent on average 6 minutes between starting a new game, in comparison to 65 minutes for the 'active' players.

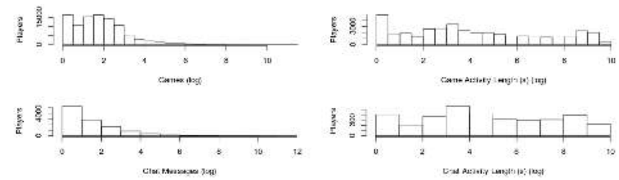

**Figure 4: Distribution of games, chat messages, and account durations (games and chat) for all EyeWire players.**

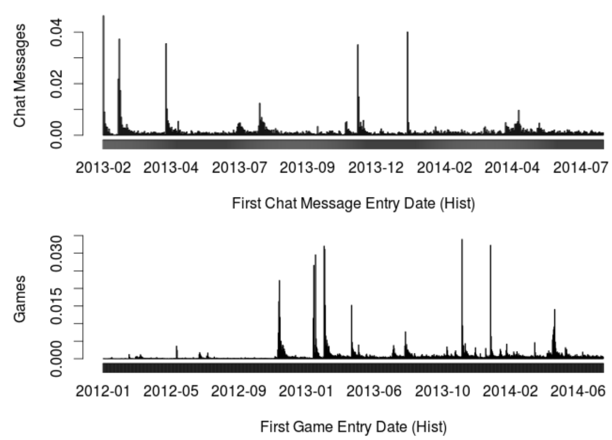


**Figure 5: Timeline of chat and gaming activity for the EyeWire platform.**

### 5.1.1 *Player Cohorts*

As shown in Figure 4, the analysis of chat and gaming account duration reveals that for gaming activity, there are many players which have a short gaming duration, whereas players chat for longer periods of time. In order to examine the retention of players within the EyeWire platform in greater depth, we used a cohort analysis method as described by [18, 19]. We apply this approach to obtain a 'chat' and 'gaming' cohort, which corresponds to the players which have had at least one recorded activity in a given month. The analysis encompasses the total lifetime of the project and assigns players to a cohort based on the month that their first activity was identified. Figure 6 illustrate the retention of players based on their activity in chat and gaming. The analysis discovered 19 chat and

| Statistic | (All Players) | Task Only Players | Talk and Task Players | Highly 'Active' Players | Command-Using Players | Non Command-Using Players |
|---|---|---|---|---|---|---|
| Players | 97,945 | 86,659 | 10,705 | 1,060 | 3,152 | 7,559 |
| Task Entries | 4,005,244 | 1,272,081 | 2,733,163 | 2,007,346 | 2,024,266 | 708,897 |
| Chat Messages | 835,130 | - | 799,338 | 705,680 | 728,380 | 70,958 |
| First Task Entry | 2012-01-19 | 2012-01-19 | 2012-01-21 | 2012-01-21 | - | - |
| First Talk Entry | 2013-02-16 | - | 2013-02-16 | 2013-02-16 | - | |
| Last Task Entry | 2014-08-05 | 2014-08-05 | 2014-08-05 | 2014-08-05 | - | - |
| Last Talk Entry | 2014-08-05 | - | 2014-08-05 | 2014-08-05 | - | |
| Avg. Chat Messages per player | - | - | 75 | 666 | 231 | 9 |
| Avg Commands per User | - | - | 10 | 95 | 34 | - |
| Avg. Tasks completed per User | 257 | 15 | 255 | 1894 | 642 | 93 |
| Med. Duration of Task (secs) | 293 | 258 | 293 | 297 | 317 | 258 |
| Avg. Task Account Length (hours) | 1,641 | 416.2 | 1,641 | 6,513 | 2,511 | 1,278 |
| Avg. Chat Account Length (hours) | 495.8 | - | 495.8 | 4,788 | 1,069 | 256 |

**Table 2: General Dataset Statistics**

and 32 gaming cohorts, and the rise and decline of each cohort depicts the sudden intake then drop-off of player activity within each of the monthly cohorts.

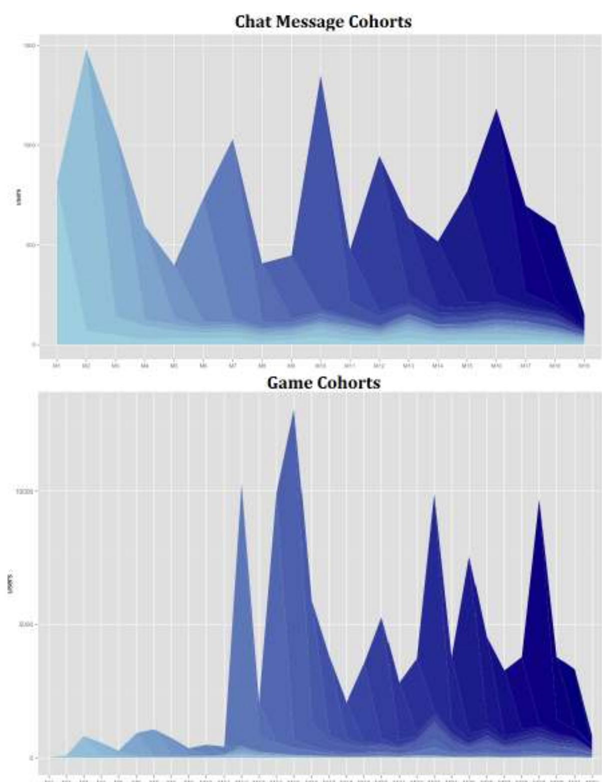


**Figure 6: Player Cohort Analysis. Chat Cohort - 19 cohorts. Gaming Cohort - 32 cohorts**

The peaks identified in the chat and gaming player cohorts shown in Figure 6 correspond to the peaks of first activity show in Figure 4. This 'rise and fall' are a usual characteristic of an online community; new players join, perform several tasks, then slowly become less active, with only a few players remaining active and continuing to participate. The fluctuation in cohort size is typically due to external factors influencing user sign up, which in the case of EyeWire may be a result of competitions or external announcement from other media sources e.g. blog, social media).

Month 11 (M11) of the gaming cohorts corresponds to month 1 (M1) of the chat message cohorts, and as Figure 6 illustrates, the uptake of 'gaming' players was relatively small until month 11, which may be an indication of the impact of chat on gaining new players. In month 23 there was a noticeable increase in several cohorts, suggesting a revival of existing players. In comparison to this, although the 'chat' cohorts have a similar profile in terms of initial user drop off, cohorts tend to retain a sub-set of the initial set of players longer than the 'gaming' players, which suggests that chat may act as a feature to sustain participation, or that these players represent the core community of individuals which participate in chat over several months, or even years.

### *5.1.2 Gaming, Chat and Commands*

The in-line chat mechanism in EyeWire is an integral feature which offers players the ability to discuss and chat with other members, in real-time. Embedded within the chat system are a list of 'chat commands' which players can use to perform a game or communication related event. For instance, players are able share personal statistics ('/me'), post private messages ('/pm'), list, join teams, and send public broadcasts to specific groups ('/team', '/gm'). As the purpose of the chat interface was designed to facilitate communication between online players, we explored the role of chat with respects to a player's gaming activity. We first examined the relationship between the frequency of chat use in comparison to the number of games a player completes. Based on the set of 'active' players that participate in chat, we found a positive correlation between the number of chat messages made and the number of games completed, shown in Figure 7.

Within the set of 'active' players, we found that 29.5% of players used commands within their chat messages (3,152)[7], as illustrated in Figure 8. Examining the 'command-using players', the number of commands a player makes (normalised against the number of chat messages made) demonstrated a positive correlation with the number of games a player completes. Moreover, players that used commands within their chat completed over 6 times as many games on average (642 in comparison to 94), yet were only somewhat slower than non-command using players (317 seconds in comparison to 286 seconds).

In reference to the 'highly active' players described in Table 2, 60.3% of these players used command within their chat messages. In comparison to the 'active' players that used commands, the 'highly active' players used three times as many commands (95 commands compared to 31), with one particular player using 23,900 commands. Considering the average number of chat messages a 'highly active' player produced (666), 14.3% of their inter-

[7]3,152 represents unique uses of commands, some players may use more than one command in a message

action with chat involved the use of commands.

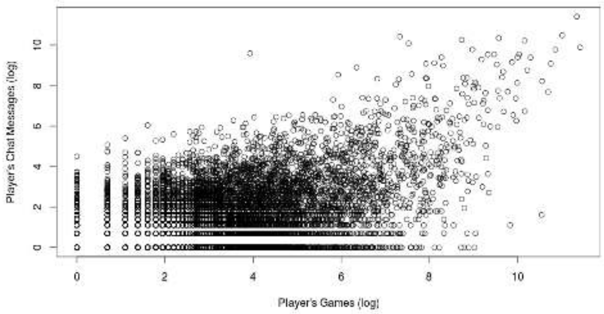


**Figure 7: Number of games completed against the number of chat messages produced. Spearman's Rank Correlation: 0.40**

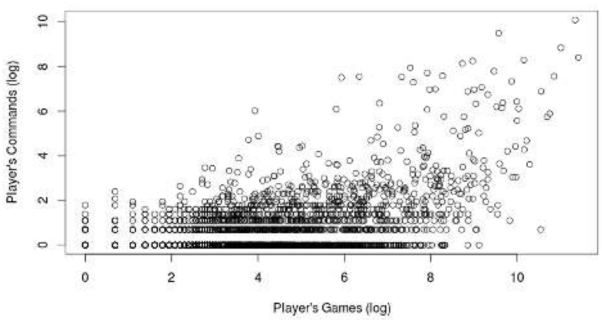


**Figure 8: Number of games completed against the number of commands used within a chat message. Spearman's Rank Correlation: 0.45**

## 5.2 Chatting During the Process of Gaming

Our initial analysis identified that players who engaged in chat messages were more likely to complete more games. Based on this, we investigated the details of how chat was being used by players during the gaming process. Specifically, we were interested in at what point do players engage with chat when they are playing the game.

A game represents a duration of player interaction, but also run in parallel with the production of chat messages. In order to examine how chat messages affect the process of gaming, we separate the chat messages with respects to the various stages during the process of completing a game. Table 4 contains chat messages corresponding to the different stages of gaming, as described in Table 1. In total, 96,021 (12%) chat messages out of a possible 799,338 were found to coincide at the same time as a game, and those which had coinciding chat messages had an average duration of 464 seconds, in comparison to 364 seconds.

Given that the purpose of this analysis was to consider the relationship between chat messages, their posting time, and the effect on a player's gaming activity, we further explored a features related to the characteristics of the chat messages.

First, we focused on the length (in characters) of a chat message with respects to the stages of gaming. As Figure 9 illustrates, the length of a chat message are short (characters). Messages before (Q0) and at the start (Q1) of a game are shorter than those during (Q2-3) or at the end (Q4). We also found that chat messages written after (Q5) a game has been completed are shorter in length than

| Stage | Messages | Associated Games | Avg. Message Len. (Chars) | Avg Class. Duration (Secs) | Commands Used |
|---|---|---|---|---|---|
| Before (Q0 ) | 19,942 | 11,811 | 26 | 142.6 | 11,271 |
| Start (Q1) | 13,154 | 23,583 | 25 | 865.6 | 17,070 |
| During (Q2-3) | 29,783 | 50,143 | 30 | 461.9 | 45,540 |
| End (Q4) | 14,497 | 21,075 | 30 | 344.0 | 22,660 |
| After (Q5) | 18,735 | 12,236 | 20 | 177.51 | 8,972 |

**Table 3: Chat Message Stages: Content**

at any other stage. Second, we examined the duration of a game based upon how many chat messages were produced with respects to the 5 different stages. As Figure 10 shows, we found a normal distribution with respects to a game duration at Q0, Q1, and Q2-3. However games took more time to complete if they received messages at the start (Q1) or during the gaming process (Q2-3) (237 seconds), compared to those that have discussion either before (Q0) or after (Q5) ( 60 seconds).

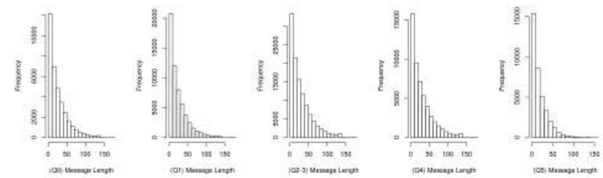

**Figure 9: Distribution of Chat Message Length (Characters) by Stage**

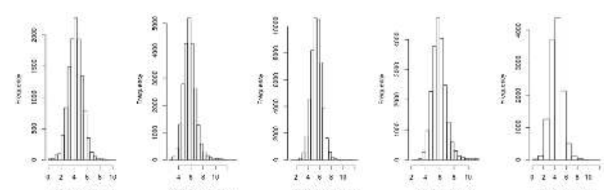

**Figure 10: Distribution of Games Duration (Seconds) by Stage**

### 5.2.1 *Chat Message and Command Use*

As discussed in Section 3, the use of in-chat game commands are an integral feature of the EyeWire chat environment. Table 4 shows the 5 most frequently used chat commands identified during each stage of the gaming process, which was computed by aggregating all chat messages which corresponds to the different stages of gaming. Across all five stages, '/gm', a command which allows players to message players assigned to a specific group (for example '/gm teamA hello world') was the most used command, which indicates the presence of teamwork and player coordination.

We also found that the '/list' command, used to list online players, was used frequently before (Q0) and after (Q5) a game was performed. The '/team' command was also identified as a popular command at the start (Q1) and during a game (Q2-3). The '/team' command provides players with a list of all teams currently active and available to join, and was introduced in the command list in order to allow players to form and conduction team work during

| Stage | Cmd#1 | Cmd#2 | Cmd#3 | Cmd#4 | Cmd#5 |
|---|---|---|---|---|---|
| Before (Q0) | gm | list | me | team | help |
| Start (Q1) | gm | team | who | list | msg |
| During (Q2-3) | gm | me | team | list | silence |
| End (Q4) | gm | team | list | me | help |
| After (Q5) | gm | list | me | silence | who |

**Table 4: Chat Message Boundary Boxes: Commands Used**

competitions and events. However, this has now remained a feature during non-competition time.

During (Q2-3) the gaming process '/silence' was identified as a highly used command, and was also frequently used after (Q5) the completion of a game. As the '/silence' command mutes all chat messages and interruptions, we assume that players used this command in order to reduce distractions during the process of gaming, then re-enabling chat after the game was completed. The findings also reveal that '/help' was common before (Q0) and at the end (Q4) of the gaming process, the latter may indicate players who are unsure of their gaming activity.

To consider the context of command use during a gaming session, we constructed 'command chains' used by players during a game session. For each player we obtained a chronological ordered list of chat messages and extracted the chains of commands used during each gaming session. We then compared the chains of all users in order to identify the most common chain of commands. The average number of commands used during a gaming session was 3, with the longest chain of commands being 126. The most common chain of commands used was '/me /me /me', followed by a number of other single command chains. Omitting all command chains that contained three of the same commands, we found that '/gm /silence /gm' and '/list /silence /list' were commonly used by players, and 91% of the chains that contained the '/silence' command as the second command were written at the start (Q1) or during (Q2-3) the gaming process. Given that the '/silence' command was highly used during gaming, and featured within the commonly used command-chains, it may indicate that chat could be an interruption during gaming.

### 5.2.2 Chat Message Content and Vocabulary

In order to provide context to the chat messages, we examine the text of the messages to identify common vocabulary and terminology. As part of the pre-processing we remove all stop-words and stemmed all remaining words. We applied text analysis to identify and remove common lingua from the chat messages. The text analysis used a corpus of keyword pairs as described by Agichtein et al. [2] which helped identify messages related to question answering and help. The analysis revealed that messages during (Q2-3) and after (Q5) a game had less messages that contained keywords related to questions or help, and contained more emoticons than messages in other stages of the gaming process.

In order to examine the content of the chat messages we computed the topic models for each of the chat message boundaries using LDA [5]. The topic modelling used Griffiths and Steyvers approach [20] to determine the number of topics for each of the chat message boundaries. For each topic we collected the top 8 terms; Table 5 shows the number of topics identified within each boundary and the common 5 topics identified, filtered by the frequency of identified terms. With reference to the identified terms of all chat boundaries listed in Table 5, the chat discourse identified is related to general conversation about playing EyeWire as opposed to domain specific discourse or scientific language or terminology.

The number of topics identified indicate that before (Q0) and at the end (Q4) of a game the discourse was more diverse. During Q0 and Q1 the topics were varied from players saying hello to discussions of team play and strategies. Similarly, during Q4, messages contained team discussion and messages about the game just completed. In contrast to this, during (Q2-3) and after (Q5) the game, chat was focused around fewer topics, with terms related to finishing or ending a player's EyeWire session. Both Q2-3 and Q5 contained fewer topics than other stages, which may be a consequence of players concentrating on the game or talking about similar things during a gaming session, and within Q5 players were using chat to say their farewells to other players. As saying goodbye was a common term across topics during Q5, it may indicate that players do not perform multiple games within one session.

In terms of topics and commands, we found that players used different chat commands at the various stages of completing a game, relative to the topic context. our findings suggest that during the gaming process, players used commands such as '/silence' in comparison to messages made before and after the game, which tend to focus on the use of group or team commands such as '/gm', '/team', and at the start of the game, the '/list' command was identified across many topics, which is a server command to list all players online at that point in time.

## 6. DISCUSSION

In this section we assimilate the results described in the previous section and discuss their implications in terms of the three questions asked in Section 1. We then consider our findings in the wider landscape of other citizen science studies.

*(1) What is the relationship between real-time chat and the gaming process?*

The analysis of how players interacted with EyeWire has provided insight into the use and relationship between real-time chat and gaming, surprisingly only 10% of the players participated in both chat and gaming, a group that we labelled the 'active players'. In comparison to other citizen science platforms which contain an active user group of over 40% [27], the low proportion of players identified in EyeWire is unexpected given that the chat interface is integrated and in-line with the gaming interface. We discuss this in more depth later in this section, specifically with respect to the content and topics within a chat message.

The analysis of the set of 'active players' found a positive correlation between the number of chat messages written and the number of games completed. In addition to this, active users sustained a much longer account duration for chatting and gaming. In comparison to non-chatting players, the 'active players' completed more games and sustained a longer game and chat account duration.

With respects to the duration of a game, while it is reasonable to assume that the time required to complete a game is relative to the number of chat messages a player makes during the gaming process, we question whether the additional discussion aids the accuracy of the game. Although we are not able to identify individual score ratings for each game, we assume that the chat messages provided some benefit to players during their gaming process, given that players with many games produced many chat messages and played for longer. We also noted that more broadly the relationship between the churn of players with respects to chat and gaming; the influx of new players as shown in Figure 6 corresponds to a significant increase of games being played.

*(2) What do players use real-time chat for?*

Based upon the first question described above, we focused on *how* chat was being used by the set of 'active' users, specifically, by analysing the content of their chat messages and how they are used around the gaming process. By separating the chat messages

| Boundary | Total Topics | Topic#1 | Topic#2 | Topic#3 | Topic#4 | Topic#5 |
|---|---|---|---|---|---|---|
| Before Game | 40 | last, week, thing, hi!, page, next, blog, post | danni, cube, know, cell, good, fun, for, maybe | team, join, yeah, branch, cya, i'll, need, think | scount, /gm, reap, i've, tbs, nub, branch, give | lol, use, yeah, make, also, must, super, cube |
| Start of Game | 33 | thank, guy, yay, know, think, now, love, ... | trace, cube, lol, see, can, get, cell, just | /silence, nie, like, one, help, tutorial, right, know | just, like, cell, get, work, one, see, point | lol, /team, /list, just, scout, one, yeah, can |
| During Game | 24 | look, cube, see, check, merger, need, get, let | well, /silence, get, just, nice, think, one, hey | lol, i'm, like, yeah, cube, think, ..., one | can, like, help, compute, game, see, use, cube | i'm, work, get, cell, can, like, now, good |
| End of Game | 50 | cell, just, lol, like, new, maybe, eye | lol, like, cube, also, good, must, use, person | trace, click, use, mouse, sweet, just, dream, like | cube, can, /help, one, brain, just, click, like | team, lol, just, /team, nseraf, get, can, one |
| After Game | 22 | hey, yes, nice!, cya!, i'll, gtg, judt, guy | point, cube, trailblaz, just, haha, today, got, lol | one, yea, good, lol, night, just, thnx, I'll | /gm, scout, admin, slow, load, just, look, very | bye, hehe, cube, yeah, hey, i'm, scout, while |

**Table 5: Chat Message Boundary Boxes: Topic Models**

into five stages of the game process offered a granular view on how chat was being used by the 'active' players, both in terms of chat content and volume.

Only 12% of chat messages were written during a game was being performed, and of these games, the average time to complete was over over 100 seconds longer than those without chat messages. The categorisation of chat messages revealed several notable characteristics, in particular, the duration of a game and the number of games performed. Separating the chat messages into five stages during games, namely, before (Q0), at the start (Q1), during (Q2-3), at the end (Q4), and after (Q5), we found that the volume of messages tend to fluctuate depending on the stages of games, as does the length of the message. Games which received many messages during (Q2-3) tended to take much longer to complete, where as those which received discussion before and after were substantially shorter. We also observed a symmetry between the length (characters) of the chat messages before and after the game, and that during a game, messages tended to be longer, which may explain why games that have many messages during the gaming process time may take longer to complete.

The analysis revealed that game commands were a key feature that players used in chat. We found that within the set of 'active players, 50% of players used commands in their chat messages, and the 'command-using' players contributed to 74.1% of the total games completed and 88.3% of chat messages written. In comparison to the 'non-command players', the 'command-using' players completed seven times as many games, and sustained a longer account duration than 'non-command-using' individuals. Furthermore, we found that more than 60% of the players that were deemed 'highly active' (those with account durations longer than consecutive 30 days) were using commands within their messages.

Looking at the use of game commands from a temporal perspective, the analysis of the five stages of chat messages revealed that the group message ('/gm') command was most common throughout the gaming process, used to issue commands to specific groups that a player affiliated themselves with. Players also used the '/list' command before and after a game to find other players that were active and online, and we found that those that chatted after this command was issued (during a game) took on average two times longer to complete a game. Similarly, the '/silence' command was used frequently during the gaming process, used to disables the chat message box and stops any chat notifications from popping up on the gaming interface. We found that the use of this command was often used in the command chain '/list /silence /list', an indication that players were seeking to see if other players were online before initiating into a new game.

Another notable use of commands was the use of the '/team' command at the start or during a game. The use of this command is related to the various team-based competitions that EyeWire run periodically, which allow players to form teams and compete against each other for leader board points. With reference to the timeline of activity illustrated in Figure 5, we found that the periods of more activity in both games and discussion occurred when the EyeWire team ran team-based competitions, which also corresponded to a higher frequency of game command use. These results suggest that allowing players to access gamification features within chat such as teams, messaging specific individuals, or providing players statistics of their performance appeared to be important for engaging player; those that used commands were responsible for more games, and had a longer account duration.

*(3) Does real-time chat facilitate discourse and collaboration between players?*

The analysis revealed that the content of chat messages offered an additional perspective on how players were using chat within EyeWire. From a systems perspective, the use of game commands in chat was identified as a feature which distinguished the highly active players, with a smaller proportion of players who used thousands of commands during their gaming sessions. Furthermore, the categorisation of chat messages during the different stages of the gaming process revealed that certain commands were more popular commands.

The use of topic modelling helped identify the vocabulary and discourse that occurred during the different stages of game. Across all stages, the terms identified in the topic models suggest that discourse was predominantly about playing the game, or related to general discussion. In comparison to other studies of vocabulary and language in online communities and citizen science projects [13, 27], discussion in EyeWire does not appear to be domain specific, given that there are few or no terms related to medical or neuroscience terminology.

The insight gained from the topic modelling along with the previously discussed results raises questions about the role of chat within EyeWire, and it's overall impact on the performance of completing games. While we observed a positive relationship between players that engaged with chat messages and the number of games they completed, this only accounted for one tenth of the total user population. Accepting that the distribution of players and chat messages follows typical power laws observed in Web systems, we still question how chat for these 'active' players impact their overall engagement. On one hand, it appears that players that engaged in chat, and specifically using game commands in their messages performed the most games, over the shortest space of time, for the longest account duration period. On the other hand, discourse within chat appears to be very generic, 'chatty', rather than scientific of domain specific knowledge, which may indicate that chat is not directly facilitating scientific discovery, unlike other citizen science systems [27].

## 6.1 Broader Implications for Citizen Science

In studies of other online communities and citizen science platforms [8, 27], volunteers can be categorised broadly by those that contribute only to completing a task (or game), and those that complete tasks as well as participate in discussion. Similarly, in EyeWire we observed these two categories of players, those that only play the game, and those that engage with real-time chat the game. Taking into account the differences between gamified and non-gamified citizen science platforms and their approach to facilitate community discussion (e.g. real-time vs forums), findings suggest that providing participants with the capabilities of interaction and discussion is beneficial for the project. However, as the analysis of the EyeWire chat revealed, there are several important insights with respects to how players use chat.

In comparison to other citizen science platforms which observed the discussion of science [27], the vocabulary identified in EyeWire suggests that chat was used by players for general discussion, as a coordination service, often facilitated by the use game commands. We assume that the primary reason for this distinction is due to the *real-time* aspect of chat; scientific discourse require in-depth discourse, which is difficult to achieve within a live, transitive environment. Arguably, this is beneficial for EyeWire, as such in-depth discourse may distract players, inhibit productivity and hinder overall system progress. In addition to this, the integration of in-chat game commands in EyeWire were found to improve player productivity, which are features not found in non-gamified citizen science platforms.

The analysis of the chat discourse also raises questions about the motivations and reasons of player participation. Previous studies [29, 7, 33] alongside the internally-conducted 'player study' (as described in Section 3) found that volunteer motivations were driven by their love of science, or being able to contribute to an important area of research. In such studies, the discourse revealed participants who were talking *about* science, adopting scientific terminology. However, the analysis of the vocabulary of chat messages in EyeWire suggests that unlike other citizen science platforms, the vocabulary of chat messages are less concerned with scientific discussion, but rather general communications; contrary to the results of the player survey. Although deeper discourse analysis would be required to examine this in more detail, the temporal nature of and real-time chat may invoke motivations and player behaviour to engage in lightweight discussion and team coordination, rather than facilitate longer, sustained discussion, leading to scientific discovery.

In general, the findings suggest that there are various trade-off for including and excluding certain features when developing a citizen science platform. If the goal of the system is to achieve a sustained community of participants who actively contribute to scientific discussion, then real-time chat may not be the best feature to facilitate this. Alternatively, if the platform requires an engaged and communicative community of volunteers, then the use of real-time chat can be helpful. However, if the goal is to complete as many tasks as possible irrespective of how long a player remains active for, then designers should not concern themselves with such features of chat and discussion, but instead concentrate on interface design and simple workflows.

## 6.2 Limitations

The analysis predominantly focused on using quantitative methods to understand the role of chat within EyeWire, and its relationship with a players gaming experience. Whilst this provides a detailed view of how players interact, we consider the use of more in-depth qualitative analysis of player activity to further understand a player's interaction with chat, and how it relates to their gaming experience. Additionally, we are aware that player participation may be affected by the launch of competitions and special events, thus in order to understand this, we would need to perform interviews with EyeWire players which participate in these events.

# 7. CONCLUSION

In this paper we analysed the behaviour of players in the citizen science game, EyeWire. Driven by the question of understanding the behaviour and interaction of players in EyeWire, we examined over two years of gaming and chat data, and found several features which distinguish players based on the way they interact and communicate with the real-time chat interface. Surprisingly, less than 11% of players used the real-time chat interface, however those that did were more likely to complete a greater number of games than those that did not, as well as remain active on system for longer.

Furthermore, players that utilised advanced chat functionality such as in-built game commands via the chat interface contributed to a substantial proportion of the games and chat messages created. These players were also those that remained active for the longest duration of time. Unlike other citizen science platforms, EyeWire's real-time chat predominately catered for general discussion, team communication, and self-monitoring, without showing signs of scientific discourse. However, this could be considered as a desirable trait, given that those that engage in chat took longer to complete a game, and having scientific discourse would only further decrease player productivity.

Considering the findings more broadly in the context of citizen science and online communities, EyeWire has become a successful system not only because of the creativity and functionality of the platform, but also due to a willing community of players, who are supported by an equally committed team of developers and scientists. Gaining and retaining an active community of participants, players, or volunteers requires more than just implementing gamification techniques.

As studies have shown [27], the characteristics of citizen science communities are unique, and models to describe user behaviour often only applicable the system under observation. Studies such as the one presented in this paper help understand the characteristics of the expanding eco-system of citizen science projects. In the same vein as micro-level lab-based experiments of socio-technical systems[22], studying citizen science projects offer insight into human behaviour and interaction at web scale. Our future research will involve the analysis of additional citizen science projects in order to establish a wider set of user characteristics and also develop the methodological and analytical repertoire required for unified citizen science analytics.

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