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Science Gamers, Citizen Scientists, and Dabblers: Characterizing Player Engagement in Two Citizen Science Games

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ABSTRACT
Our understanding of volunteers' engagement in citizen science games is limited, and the impact of gamefulness on volunteer engagement requires further investigation. In this study, we adopted a data-driven approach, exploring volunteers' psychological and behavioral engagement in two citizen science games: *Forgotten Island* and *Happy Match*. We performed a cluster analysis based on the quantity and accuracy of volunteers' contributed data and conducted a qualitative content analysis of player survey responses to open-ended survey questions. We combined the results of the clustering analysis and the content analysis to identify and characterize three player groups based on their engagement patterns: "science gamers," "citizen scientists," and "dabblers." Our identification of this three-group typology of citizen science players enhances our understanding of volunteers' contribution and engagement patterns, and we provide design recommendations that may help scientists and designers to refine their own citizen science game initiatives.

1. Introduction

Citizen science, a technique for involving members of the public in scientific inquiry, has become a popular approach for crowdsourcing scientific problems (Bonney et al., 2014; Cohn, 2008; Wiggins & Crowston, 2011). Participation patterns in citizen science projects vary across projects, some of which may risk cancellation or failure if they cannot reach sufficient volunteers (Tinati et al., 2017). Recruiting and retaining more volunteers has become one of the biggest challenges for the sustainability of citizen science projects (Díaz et al., 2020). Researchers and designers have proposed applying game design techniques to enhance volunteers' engagement in citizen science projects (Preece, 2016). Several citizen science initiatives, such as *Eyewire*[1] and *Foldit*,[2] have successfully deployed systems with game-like elements to support scientific inquiry (Curtis, 2015; Schrier, 2016). Such systems are sometimes referred to as "crowdsourcing games," "games with a purpose," "human computation games," or "knowledge games," because they use crowdsourcing, collective intelligence, and other distributed approaches to promote learning and problem-solving in scientific domains (Schrier, 2016).

Many different approaches exist to employ game elements in non-game contexts (Morschheuser & Hamari, 2019; Ponti et al., 2018). Varied attempts to integrate serious tasks with games have led to a loose, ambiguous definition of "gamefulness" in this context. "Gamefulness" refers to a mix of experiential and behavioral qualities of gaming (Deterding, Sicart, et al., 2011), which is sometimes used to connect play experience with particular kinds of systems (McGonigal, 2015). Landers et al. (2019) decomposed gamefulness into three concepts: gameful design, gameful systems, and gameful experiences, where a "gameful system" is an artifact with intentionally designed game characteristics, a "gameful experience" is a psychological state that occurs as a result of a player's interaction with a gameful system, and "gameful design" is the design process that results in the creation of a gameful system. We consider citizen science games to be gameful systems (Harteveld et al., 2016; Landers et al., 2019), having many of the elements found in commercial games, for example the mechanics, aesthetics, and story that comprise some of the essential elements of games (Hunicke et al., 2004; Schell, 2008).

Citizen science games are dual-nature systems with both scientific and game characteristics, and so they have the potential to attract different kinds of volunteers than conventional citizen science systems (Tang & Prestopnik, 2019); understanding volunteer engagement patterns in citizen science projects can provide meaningful guidance for recruiting and retaining volunteers (Dowthwaite & Sprinks, 2019; Pejovic & Skarlatidou, 2020; Sauermann & Franzoni, 2015; Spiers et al., 2019). Participants may be attracted to a citizen science game primarily for its perceived entertainment value, or may appreciate its educational, altruistic, or intellectual aspects. During play, those with an inherent interest in science may find themselves becoming engaged and enchanted by mechanics, aesthetics, or story, while those seeking

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entertainment may come to appreciate embedded scientific content. The reverse might equally be true: participants with a strong interest in entertainment may see an embedded science task as unwelcome or tedious, and participants who are mainly interested in science might perceive the game's playful elements as distracting or annoying. Prior research on citizen science games has mainly examined motivation for volunteer participation (Schrier, 2016; Tinati et al., 2017), with some researchers focusing on the relationship between motivation and engagement (Ponti et al., 2018). Yet, limited research has explored or analyzed players' engagement patterns with specific citizen science games (Phillips et al., 2019). These gaps in the literature suggest a need to characterize participants' psychological and behavioral engagement with citizen science games to better understand how to recruit and retain volunteers for citizen science projects.

One challenge is that games designed for scientific purposes take a variety of forms, from the relative simplicity of adding a few game-like elements such as points or badges to a non-game activity, to the sophistication and complexity of building a full-fledged computer game (Deterding, 2014, 2015). Landers et al. (2019) proposed a continuum of gameful systems, from "non-games" to "games," in order to characterize gameful systems with varied game elements, which could include features like collectible rewards, power-ups, enemies, obstacles, story characters, interactive narrative structures, in-game economies, animation, sound effects, dynamic music, complex game levels, and more.

Another challenge is that the individuals who play citizen science games vary as much as the games they play, and there is limited information about how different kinds of players engage with different kinds of citizen science games. A data-driven exploration of player engagement will not reveal all there is to know about citizen science game players, but it can be a useful step toward understanding gameful citizen science systems and the individuals who choose to engage with them. With this in mind, we set out to address the following questions:

1. What forms of player engagement can be identified beyond the homogenous-seeming descriptor, "citizen science game players"?
2. How do different types of players engage with gameful systems that have varied levels of gamefulness?

By answering these questions, we aim to help game designers and citizen science researchers better understand who players are and what kinds of gameful systems will engage them. We utilized a relatively well-studied citizen science system, *Citizen Sort*,[3] which features two games, *Happy Match* and *Forgotten Island*, situated in a life-sciences context. In these two games, players are asked to perform a taxonomic classification activity on photos of living things, with the end-goal of classifying to species. We argue that these two games occupy different positions on Landers et al.'s (2019) "game to non-game" continuum, creating an opportunity to explore and compare how different players might engage with two unique, yet related gameful systems.

In the next section, we present a literature review on player types, player engagement, and gameful systems. Section three provides a detailed overview of the two games that are the focus of this study, including our rationale for placing these two games in different places on the continuum. Section four introduces our research design and reports our data analysis results. Section five compares and discusses various design recommendations and strategies to fit different types of game players. Section six concludes the findings of this research.

2. Related work

2.1. Player types

Landers et al. (2019) noted that, "User knowledge, skills, abilities, and other characteristics, as well as the situational contexts in which gameful systems are deployed, moderate the effectiveness of those gameful systems in creating gameful experiences and bringing about other psychological effects," (p. 88). We cannot know the totality of a system's effects without understanding the people that use it. Therefore, knowledge about players is critical to the successful design and implementation of citizen science games and can provide meaningful insight into the experiences that result from player interactions with gameful systems.

Many researchers are interested in volunteers' motivation for participating in citizen science (Maund et al., 2020; Schrier, 2016; Tinati et al., 2017). For example, Schrier (2016) identified various citizen science participant motivations, including motivations for volunteering, motivations for engaging in crowdsourcing activity, motivations for engaging in citizen science activities specifically, and motivations for playing games. Various possibilities emerged, including winning extrinsic rewards such as money or prestige, engaging with specific kinds of problems, enhancing skills, passion for a project, advocacy, and desire to interact with or receive recognition from experts. Tinati et al. (2017) found that even if game elements are used in citizen science projects, volunteers' intrinsic motivation, such as aiding a beneficial cause, advancing scientific knowledge, and learning, were the highly mentioned reasons to participate. In some specific domain, such as conservation, Maund et al. (2020) identified that value for and desire to understand the environment are the primary motivation for volunteer participation in citizen science projects. Extant literature provides well-supported and conceptually beneficial understanding of various motivations for players across a broad spectrum of backgrounds, perspectives, demographics, and cultures (e.g., Schrier, 2016). These works do not attempt to classify or organize players based upon specific kinds of motivations, nor do they attempt to group players into categories based on real-world engagement, both psychological and behavioral, with specific gameful systems.

In the wider game design literature, designers do often attempt to classify players by "types." In commercial settings, players may be categorized by their demographics (age, sex, income, etc.) or other market-driven categories (Rogers, 2010; Salen & Zimmerman, 2004; Schell, 2008), though more sophisticated approaches have also been taken. Bartle (1996, 2004) famously denoted four player types: "achievers," "explorers," "socializers," and "killers." His characterization was based on players' desire to interact or act on a particular genre of game, the multi-user dungeon (MUD), and was framed on two axes: whether players act on or with others, and whether they act on or with the world. This characterization has been widely discussed and used as a game design tool and player type paradigm. With its specific focus on MUD-style games, which date to the 1970s, however, it is debatable whether the framework captures the full range of detail about players of more modern game genres, much less citizen science games.

Few researchers have theorized about player types specifically when games and serious tasks are integrated. One notable exception is the "Hexad framework" (Tondello et al., 2019; Tondello et al., 2016), which sorts players into six categories by their motivations for playing: "philanthropists," who are seen as altruistic players, not driven by rewards, "socializers," who are motivated primarily by relatedness and social connection, "free spirits," motivated by autonomy and freedom to express themselves and who act without external control, "achievers," who are motivated by competence and task completion, "players," motivated by extrinsic rewards like points or prizes, and "disruptors," who are motivated by their own ability to push boundaries and instigate change within a system.

Tondello et al. (2016) discuss specific design features that may appeal to these different kinds of users, for example point systems for players, guilds or teams for socializers, administrative and knowledge sharing features for philanthropists, etc. The Hexad framework concentrates on motivational drives for interacting with the playful parts of gameful systems, and with the exceptions of "philanthropist" players doesn't much consider player engagement with "non-game" aspects. Such engagement might include a player's personal evaluation of the task, their level of contribution, or their resulting data quality. These task-related outcomes, the purpose of most citizen science games, are not well represented in existing player categorizations, but we consider that player engagement with both task and play should be examined co-equally, using real-world play data if possible, in any attempt to describe citizen science game players or to understand gameful systems and experiences in the citizen science context.

2.2. Player engagement in citizen science games

Engagement refers to a person's cognitive, temporal, affective, and behavioral investment when interacting with digital systems (O'Brien, 2016; O'Brien et al., 2018). In past decades, HCI researchers have become increasingly interested in engagement, agreeing that user engagement is a complex construct with a multifaceted nature (O'Brien et al., 2018). Previous research has adopted different strategies to study engagement, which is often conceptualized as having a mix of underlying components (Appleton et al., 2008; Ding et al., 2017). In game literature, psychological and behavioral engagement are two dominant aspects for investigating players' interaction outcomes with gameful systems (Hamari et al., 2014).

In this research, we understand engagement to be a combination of psychological engagement and behavioral engagement in an activity. Psychological engagement indicates an individual's cognitive and affective reactions to encountered environments while behavioral engagement denotes active participation (Fredricks et al., 2004). In the context of citizen science games, psychological engagement refers to the ways a player thinks and feels about play and task in a gameful system; behavioral engagement refers to specific behaviors and actions that the player may take while playing. Taken together, explorations of psychological engagement and behavioral engagement in a given system—that is, exploration of gameful experience—can forge a holistic picture of participants in that system.

2.2.1. Psychological engagement in citizen science games

Psychological engagement in games refers to a player's feelings of fun, enjoyment, and pleasure in games, and these are usually termed as "hedonic" experience (Oliver & Bartsch, 2010; Oliver & Raney, 2011). Most game researchers agree that playing games can result in hedonic or pleasurable psychological outcomes. Some have further argued that games can also lead to a mix of cognitive and affective experiences that result in life insights or thought-provoking experiences, termed as "eudemonic" experience (Oliver & Bartsch, 2010).

Evaluating a player's psychological engagement in a game or gamified experience is a significant challenge. The internal thoughts and emotions that make up psychological engagement are difficult to measure, highly complex, and deeply intertwined. Games researchers have proposed many instruments for capturing "gameful experience," "game flow," and "engagement" in games, all of which measure multiple, interrelated constructs such as "immersion," "enjoyment," and the like (Bernhaupt et al., 2008; Högberg et al., 2019; IJsselsteijn et al., 2007; Jennett et al., 2008; Mandryk et al., 2006). Many game designers and researchers also stress the importance of Csikszentmihalyi's (1990) notions of "optimal experience" and "flow," as well as the importance of immersion (Fu et al., 2009). In the domain of citizen science games, researchers have found that players may be engaged with the fun, hedonic aspects of a gameful system, while also appreciating its eudemonic meaning through instrumental activities like helping others, discovering new things, or learning (Tang & Prestopnik, 2019; Tinati et al., 2017).

2.2.2. Behavioral engagement in citizen science games

Equally important is behavioral engagement, which, in the citizen science context, focuses upon player participation metrics. Metrics such as the duration that signed-up players remain active, how much data they contribute, and the quality of their data are important indicators to differentiate and understand behavioral engagement.

Prior research has used different measures to analyze users' behavioral engagement in various crowdsourcing activities. For instance, Füller et al. (2014) clustered users in a crowd testing community based on their idea generation behavior and social network characteristics, resulting in the identification of six types of contributors, including socializers, idea generators, masters, efficient contributors, passive idea generators, and passive commentators. Franzoni and Sauermann (2014) drew upon user contribution data from a series of crowd science projects and found the majority of contributions come from a small percentage of users. Prestopnik et al. (2014, 2017) have explored user contribution patterns across multiple citizen science games in order to understand how different kinds of players contribute to various projects. In the citizen science domain, researchers also attempted to characterize users into "professional" vs. "amateur" based on their behavioral characteristics (Dowthwaite & Sprinks, 2019).

These studies strongly suggest that while a few participants may be highly engaged—cognitively, emotionally, and behaviorally—most are not. The identification of behavioral patterns is another critical aspect to characterize player types in citizen science games.

2.3. Gameful systems

Gameful systems integrate key structures, aesthetics, and characteristics of games (McGonigal, 2015), resulting in a gameful experience for users (Landers et al., 2019). As described by Landers et al. (2019), gameful systems can exist on a spectrum from "non-games" to "games," though it is not always clear where specific gameful systems should be placed on such a continuum. While some gameful systems resemble commercially available entertainment games, others include a more limited selection of game elements. Opinions differ about whether systems with few game elements should nonetheless be considered games, or whether these are "non-games" as denoted by Landers et al. (2019). Ponti et al. (2018), looking at two well-known citizen science systems, *Galaxy Zoo* and *FoldIt*, showed how framing a system as either a game (*FoldIt)* or not a game (*Galaxy Zoo*) influenced participant reactions to various game elements such as point systems and leaderboards. *FoldIt* players noted concerns about the tension between play and science, with much debate over the scientific vs. gameplay value of high-scoring solutions in that game. *Galaxy Zoo* users, on the other hand, more frequently articulated that, "gaming is not compatible with scientific values," (Ponti et al., 2018).

Yohannis et al. (2014) identified a list of characteristics commonly presented in games and suggested a gameful system should contain at least some of these characteristics. Moreover, they argued that the degree of how gameful a system is can be measured with the amount of game characteristics included in a gameful system. Therefore, a system with a higher number of game elements is more gameful than a system with lower number of game elements. The inclusion of more or fewer gameful elements into a gameful system seems likely to have a strong influence a player's psychological and behavioral engagement with that system (Landers et al., 2019).

In the world of commercial, entertainment-oriented game design, several important elements help to establish structure in games. Schell (2008) argues that these elements include mechanics, the operationalized rules and goals of the game, aesthetics, the game's stylistic and emotional attributes, and story, the game's narrative. These three highly visible elements are implemented via less visible but no less important game technology, which could be a digital technology, but might also be cards, coins, playing pieces, or almost anything else. Hunicke et al. (2004) proposed a similar conceptualization, the MDA framework, which is notable for theorizing about the interrelatedness of various game elements. The MDA framework emphasizes the role of mechanics and aesthetics, treating story as an aspect of aesthetics. In the MDA framework, the dynamics of the game system—the way that various elements work together during play—are considered as necessary to fully understanding the true nature of a game.

Deterding et al. (2011) have suggested that while play represents a kind of free-form, open ended activity, games are more structured and rule-bound, characterizing different kinds of games along a "partial to whole" dimension. Landers et al. (2019) acknowledged that standardized measurement and systematic validation of these widely varied game elements is not yet available; drawing distinctions between different kinds of gameful systems still relies on subjective judgment. In the context of gameful systems, systems that selectively apply certain game elements to non-game contexts would be considered "partial" games, while more complete systems would be considered "whole" games. Landers et al. (2019), citing Huotari and Hamari (2017), suggest that, "In gameful design, effective design involves adding game elements or motivational affordances that are likely to increase gameful experience. From this perspective, the more prevalent and the more pronounced these game elements or motivational affordances are, the more gameful a system becomes," (p. 87).

No commonly agreed-upon conceptualization is available to state what constitutes a game, not to mention any method to measure how gameful a system is (Landers et al., 2019). However, the literature above suggests that games which include more (or more sophisticated, interrelated) mechanics, story, aesthetics, and play dynamics, could be considered more gameful than games that adopt a more limited approach in the use of such elements.

In section three, we distinguish between two citizen science games, arguing that they occupy different positions on Landers et al.'s continuum from "non-games" to "games." The first of these, *Happy Match,* is limited in its use of various game elements, making it a less gameful system than the second, *Forgotten Island*, which includes sophisticated dynamic interactions between aesthetics, mechanics, and story. These two games will become the basis for our exploration of citizen science player types and their engagement in later sections of the paper.

3. System overview: *Happy Match* and *Forgotten Island*

This research draws upon a long-standing project, *Citizen Sort*, developed and launched in 2012 to facilitate HCI-oriented research in the citizen science domain. In the years since its launch, *Citizen Sort* has attracted more than 5,000 users. It features two games that are the focus of this current study: *Happy Match*, a photo-matching quiz game, and *Forgotten Island*, a point-and-click adventure game.

3.1. Citizen science task

Happy Match and *Forgotten Island* share the same citizen science task: taxonomic classification of living organisms (see Figures 1 and 2). Players engage with the classification task by answering questions about photographs of living things taken in the field by scientists. Players assign a selected "state" to a specific "characteristic" of the pictured organism, a pairing known to biologists as a "character-state." By identifying enough character-states per photo, the depicted organism can be identified to species. When aggregated in large numbers and associated with additional metadata such as a geographic location or timestamp, such identifications can be used to explore scientific questions about migration patterns, ecosystem health, environmental impacts, and more. *Happy Match* and *Forgotten Island* can be set up to classify a wide variety of species; the versions of the games used for this research were focused on moths.

Character-state "decisions" are the most granular level of data available for understanding a player's behavioral engagement in the *Citizen Sort* system. A decision is a single instance of a player answering a character-state question, e.g., "The *state at rest* for this image is *spread*." To classify a single moth to species, a player must answer four questions, each of which is counted as one decision. In a game of *Happy Match*, a player makes 40 total decisions (four decisions per photo, ten photos per game). Finishing *Forgotten Island's* story requires about 320 decisions (four decisions per photo, about eighty photos total). Decisions are recorded as they are made, allowing later analysis of partial playthroughs and even partial classifications. Players can play as many games of *Happy Match* as they would like, and some players have played the game many times. Players can likewise continue playing *Forgotten Island* and can classify additional photos once the story has concluded.

Happy Match and *Forgotten Island* are both seeded with known, gold standard photos that have been previously classified by trained scientists. In *Happy Match*, two of the ten photos in a game will be gold standard photos. In *Forgotten Island*, on average one of every five photos will be a gold standard photo. Players are not made aware when they are classifying one of these photos until after the photo is classified completely. The gold standard photos allow scientists to evaluate how well a player performs the task, and therefore whether their overall data is likely to be usable or not. Other than slight differences in the number of photos displayed at a time and their manner of presentation, the classification task in *Happy Match* and *Forgotten Island* is identical.

3.2. Gameful systems: Happy Match and Forgotten Island

We consider *Happy Match* and *Forgotten Island* to occupy different places on Landers et al.'s (2019) continuum from "non-games" to "games." In the rest of this section, we

Figure 1. The *Happy Match* classification screen is organized around characters (the main question at screen top) and states (the possible answer choices in the row at screen bottom). Players answer the question for each of the ten moths shown. The version of *Happy Match* shown asks four questions total: "What is the shape at rest?" "What is the forewing main color?" "What is the forewing highlight color?" "What is the wing pattern?"

Figure 2. The *Forgotten Island* classification screen asks players the same character-state questions and provides the same answer choices as *Happy Match*. The interface is aesthetically different from *Happy Match* because of the role of story and other gameful features in *Forgotten Island's* game play.

describe from the standpoint of story, aesthetics, mechanics, and dynamics (Hunicke et al., 2004; Schell, 2008) how the mix of these elements places *Forgotten Island* further along the continuum toward "games" than *Happy Match.*

3.2.1. Story

Forgotten Island takes place on a mysterious island that has been rocked by an explosion, blasting the island's biology lab to smithereens. Specimen photos rain down across the landscape, and the player must repair the damage and re-classify the scattered photos, all while unlocking clues about the events leading up to the blast. Presented in a stylized, cartoon aesthetic (see Figure 3), *Forgotten Island* is idiosyncratic, silly, and lighthearted. Players engage with *Forgotten Island's* story through the various aesthetics and mechanics of the game, and through comic book interactions where the plot is advanced, characters are introduced and developed, and dramatic questions are raised and ultimately answered.

Happy Match has no story beyond its context of scientific inquiry and discovery and the intrinsic interest that players bring to the game. For this reason, we again consider that *Forgotten Island* is positioned closer to the "game" side of Landers et al.'s (2019) continuum than *Happy Match.*

3.2.2. Aesthetics

Both games have a professional, polished, and playful aesthetic, but we consider *Forgotten Island* to have a more gameful aesthetic than *Happy Match*. *Forgotten Island's* graphics include quirky locations to explore, a stylized overview map, cartoon robot characters, fantastical gardens to grow, and stylized interfaces to interact with (see Figure 4). *Forgotten Island* also includes a fully realized sound design, including music, sound effects, and ambiance for all locations in the game.

Happy Match's visual aesthetic (see Figure 1), on the other hand, is more strongly influenced by its underlying scientific task. The game visuals emphasize life-science themes, including imagery of growing things, natural colors like greens and browns, and naturalistic photographic elements, including the organism photographs themselves. There are few interfaces to interact with in *Happy Match* beyond the main classification interface. *Happy Match* has no sound, to better allow players to concentrate on task.

3.2.3. Mechanics

The game mechanics in *Happy Match* are similarly focused on the science task: players interact with this game by dragging and dropping photographs to bins that represent different states. Once all ten photos are classified for a given character, a new question is asked and the process repeats. These mechanics are designed to reward players for task engagement and good performance through points and leaderboard recognition on the main *Citizen Sort* website.

Forgotten Island includes the core classification activity found in *Happy Match* but is augmented by additional mechanics (see Figure 5). Players explore the island world of the game through a walking mechanic, using the computer mouse to search for equipment and items that might be useful. Points of interest can be clicked on, and the player avatar will offer his or her thoughts through cartoon "thought bubbles," with information presented in a humorous and quirky style. Players combine found items to solve puzzles in classic point-and-click adventure gameplay, also acquiring in-game currency by classifying images of living things. Currency can be spent on in-game tasks and equipment, including a cartoon gardening mechanic that is essential to restoring the island and winning the game. In *Forgotten Island*, the scientific task is presented as just one

Figure 3. *Forgotten Island* has an involved story, delivered through comic-book pages that connect to the world and mechanics of the game. The story takes about five hours to complete, and is tightly connected to the aesthetic choices of the game, as well as the various mechanics. Here, the story is presented aesthetically in comic-book fashion, and the antagonist of the game assigns various activities that will be completed via the mechanical systems of the game.

Figure 4. *Forgotten Island* features a world to explore, presented aesthetically through digitally-painted, cartoon-style graphics.

mechanic—arguably the least gameful—among many, and points (reframed as in-game currency) develop their own internal "endogenous value" (Schell, 2008) because of the way they can be used to advance the story and unlock the world of the game. Players are briefly told at the start of the game how their work will help scientists, but otherwise engage with science through the classification activity itself.

3.2.4. Dynamics

In *Forgotten Island*, players oscillate between several interrelated activities over the course of the game, including exploration of new locations, collecting items and equipment, collecting moth photographs, advancing the story, the taxonomic classification task, puzzle solving, and gardening. Each activity incorporates its own unique mechanics and aesthetics while contributing to the totality of the game. For example, gardening gives players simple "planting" mechanics to customize gardens with hundreds of different plants. The exploration activity includes a walking mechanic, where players wander the island, looking for items, equipment, and falling moth photographs to collect.

In *Happy Match*, the dynamic of the game is different, more akin to a quiz than an exploration adventure. Questions are presented in a less zany and more "scientific" aesthetic, and the game can be played over and over, with players seeking to achieve a perfect score each time. This contrasts to the dynamic of *Forgotten Island*, where the classification activity is done frequently, but always in pursuit of a tangible reward: in-game money that will be spent on new exploration equipment, plants for the gardens, or components for repairing the ruined island. Thus, the dynamics of *Happy Match* lend themselves more to players who have an inherent interest in engaging with the scientific task, while

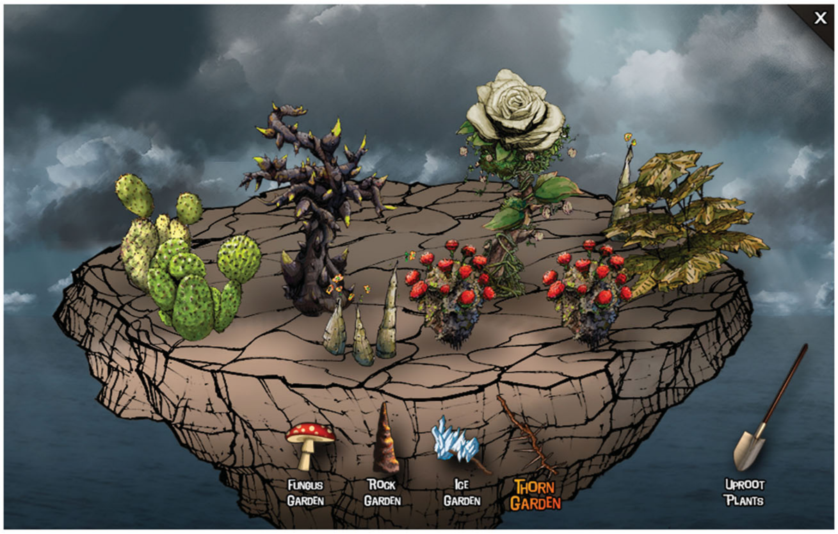

Figure 5. *Forgotten Island* includes a variety of gameful mechanics, including a gardening mechanic that allows players to express themselves while making progress towards completion of the game.

Table 1. Differences in gamefulness between *Happy Match* (less gameful) and *Forgotten Island* (more gameful).

	Happy Match (less gameful)	*Forgotten Island* (more gameful)
Story	• No included story • Lack of fully developed characters • Lack of involved character relationships • Lack of meaningful character goals • Lack of developed story world • Lack of fully realized story structure	• Fully-fledged story • Developed characters with faults and strengths • Involved (and involving) character relationships • Dramatically engaging character goals • Believably complex world building • Adherence to accepted storytelling structures
Aesthetics	• Aesthetics evoke a sense of productivity • Missing aesthetic elements, e.g., no sound	• Aesthetics evoke a sense of play • Full aesthetic realization, include visuals & sound
Mechanics	• Simple rewards like points and achievements that measure contribution • Limited modes of interaction • More like non-game software (quizzes, tests) • Focus on task	• Integrated rewards like resources and unlocks that are "reinvested" into the experience • More and more complex modes of interaction • More like video games (adventure, exploration) • Focus on play
Dynamics	• Mechanical systems don't interact; play modes feel simplistic and/or disconnected • Mechanics, aesthetics, and story not connected • Mechanics, aesthetics, or story missing • Little use of unifying themes across elements	• Mechanical systems interact; play modes feel connected, related, and cohesive • Mechanics, aesthetics, and story tightly connected • Mechanics, aesthetics, and story all fully realized • Strong use of unifying themes across elements

the dynamics of *Forgotten Island* lend themselves more to individuals who are familiar with and enjoy point-and-click adventure gameplay. Table 1 summarizes the differences between *Happy Match* and *Forgotten Island*.

4. Methods and results

The data for this study was collected from two sources. One source is the *Citizen Sort* system, where we queried all registered players' data in *Happy Match* and *Forgotten Island* from September 2012 (when the system was first launched) to April 2018. We also recruited participants to a second analysis by emailing a questionnaire link to all registered players in the *Citizen Sort* system. *Happy Match* and *Forgotten Island* players were emailed separately, each receiving slightly adjusted versions of the questionnaire (use of specific game titles, etc.) based on the game they had played. We used the questionnaire to collect players' subjective opinions about the citizen science game they had played, and the following questions were asked:

Q1. What elements or components of the game helped to keep you interested in playing the game? How so?
Q2. What elements or component of the game influenced your willingness to classify pictures of living things? How so?
Q3. Are you still playing the game? If NO, when did you stop playing the game and why?
Q4. Do you have any other comments or reactions about your experience playing the game?

We combined data queried from the *Citizen Sort* system with data collected via survey to perform a mixed-methods analysis. This was possible because the data stored within the *Citizen Sort* system is tagged with a player's email address, allowing us to associate queried play data with survey responses. We conducted this analysis in three steps.

First, we used registered users' play data queried from the *Citizen Sort* system to perform a cluster analysis based on the quantity and accuracy of their contributed data, ultimately identifying three unique clusters of players for each game.

Second, we solicited responses to a survey sent to our players via email. There were two nearly identical versions of the survey: one version asked respondents to recall their experience with *Happy Match* and one specifically asked about *Forgotten Island*. 76 players responded to our survey invitation, a 2% response rate. We conducted a qualitative content analysis, focusing on the open-ended questions and looking for themes and patterns in the data.

In the third step, we integrated the results of our cluster analysis and our content analysis to reveal additional insights about our player groups. For each survey participant, we determined which game they had played and which cluster they belonged to, and then we evaluated this mix of data, yielding a variety of insights into players' engagement, their perceptions of our two gameful systems, and, ultimately, the types of players who might be attracted to (or repelled by) citizen science games.

4.1. Analysis #1: Cluster analysis of players' behavioral engagement

Our cluster analysis used existing play data from *Happy Match* and *Forgotten Island*. The *Citizen Sort* system collects a variety of information about how players play and the scientific information they provide. Because players were recruited via citizen science-oriented publicity efforts, the stored data reflects a real-world sample of players.

For the purposes of analysis #1, we relied upon two behavioral engagement metrics recorded by the *Citizen Sort* system: 1) contribution quantity (how many decisions a player made) and 2) contribution accuracy (the percentage of correct decisions among all decisions a player made). The data used for this analysis was retrieved by running a series of SQL queries against the *Citizen Sort* system database.

As noted in Section 3.1, when a player answers a question about a photo, this is counted as one decision. In *Happy Match*, players are presented with ten photos to work on at one time, whereas in *Forgotten Island*, players work on a single photo at a time, answering all four questions about it before moving on to a new photo. *Happy Match* asks players to begin classifying photos immediately upon starting the game, while *Forgotten Island* exposes players to about twenty-minutes of gameplay before introducing the classification task. We therefore considered that players who had completed at least ten decisions in *Happy Match* and at least four decisions in *Forgotten Island* had sufficient exposure to the games. We removed 183 players from 2,512 *Happy Match* players and 38 players from 1,550 *Forgotten Island* players because they did not complete enough decisions. We also identified some outliers by plotting the distribution of decisions in each game. To avoid the influence of extreme outliers, we removed four players who had made more than 2,000 decisions in *Happy Match* and five players who had made more than 1,500 decisions in *Forgotten Island.* In most cases, these outliers are single accounts used by multiple people, for example a classroom of students all using the same teacher-created *Citizen Sort* account. We removed these from analysis to avoid confounds that could result from multi-user accounts. After cleaning, we identified a total of 2,325 players in *Happy Match* and a total of 1,507 players in *Forgotten Island* for cluster analysis.

Players filled out a short demographic questionnaire when they initially registered to use the *Citizen Sort* system. For the 2,325 *Happy Match* players and 1,507 *Forgotten Island* players used in the analysis, the means and medians of players' ages were similar[4] ($\text{Mean}_{\text{HM}} = 35$, $\text{Median}_{\text{HM}} = 28$; $\text{Mean}_{\text{FI}} = 32$, $\text{Median}_{\text{FI}} = 28$). In the registration questionnaire, players also answered several 7-point Likert scale questions about their interests in science, nature, and games. The results showed that our players held fairly high interest in science ($\text{Mean}_{\text{HM}} = 6.01$, $\text{Mean}_{\text{FI}} = 5.92$), nature ($\text{Mean}_{\text{HM}} = 5.60$, $\text{Mean}_{\text{FI}} = 5.28$), and games ($\text{Mean}_{\text{HM}} = 4.98$, $\text{Mean}_{\text{FI}} = 5.48$).

In *Happy Match*, the play duration of the 2,325 users ranged from one day to 12 days, with a mean of 1.25 days (SD = 0.80). The overall mean for total decisions was 86.24 decisions (Min = 10, Max = 1,598, SD = 142.21) and the overall mean for accuracy was 0.78 (Min = 0.07, Max = 1.00, SD = 0.11). In *Forgotten Island*, the play duration of the 1,507 players ranged from one day to 24 days, with a mean of 1.62 days (SD = 1.46). The overall mean for total decisions was 133.84 decisions (Min = 4, Max = 1334, SD = 205.50) and the overall mean for accuracy was 0.78 (Min = 0.00, Max = 1.00, SD = 0.13).

Building upon these two measurements, total decisions and accuracy for each player, we used K-means clustering analysis to explore the different patterns of players' behavioral engagement (Aggarwal & Reddy, 2014; Milligan & Cooper, 1987). Clustering analysis is an inductive method of classifying a set of objects into meaningful, mutually exclusive groups based on similarities among the objects (Hair et al., 2006). As a commonly used unsupervised algorithm for partitioning a given data set into a set of groups, K-means clustering was suitable to our purpose to probe the behavioral engagement patterns of players in citizen science games.

We standardized measurements before the clustering procedure to ensure that the different scales of quantity and accuracy would not affect the dissimilarity measures. This unsupervised procedure generated an initial set of centroids, following which the Euclidian distance was calculated to converge data points with their nearest centroid. The resulting clusters of objects will exhibit high internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity (Balijepally et al., 2011). Multiple rules can be used to determine the number of clusters in a dataset (Balijepally et al., 2011; Milligan & Cooper, 1985). We calculated four measures to determine the optimal number of clusters and ensure the internal validity of our analysis results: (1) the sum of the squared errors, (2) the Calinski–Harabasz index, (3) the Silhouette index, and (4) the Davies–Bouldin index

(Aggarwal & Reddy, 2014). The results of internal validity measures suggested three-cluster solutions were the best choice for grouping players in both games, which are visualized in Figures 6 and 7.

In *Happy Match* (Figure 6), three clusters emerged because this solution maximized heterogeneity between groups and homogeneity within each group. Table 2 shows the details of cluster size. The dominant group (cluster-2, green dots) had 1,610 players contributing a low number of decisions but with good accuracy. The second largest group (cluster-1, orange crosses) held 612 players contributing a low number of decisions at low accuracy. The smallest group (cluster-0, blue triangles) held 103 players contributing a large number of decisions with good accuracy.

In *Forgotten Island* (Figure 7), a three-cluster solution also emerged as the optimal solution to maximize heterogeneity between groups and homogeneity within each group.

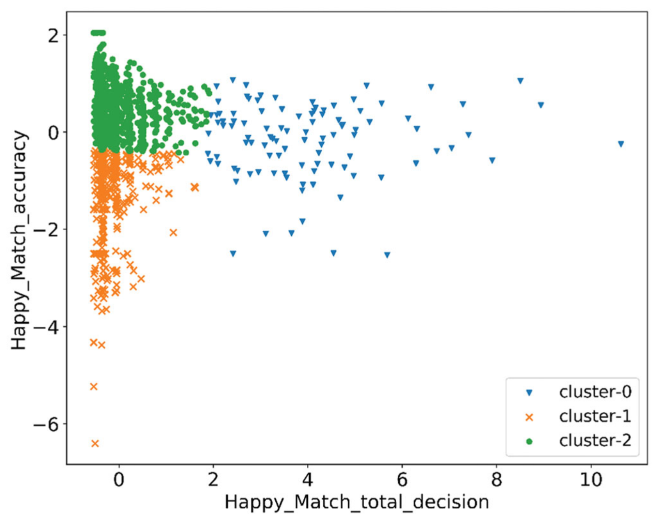

Figure 6. Plot of three-cluster solution of *Happy Match* players' behavioral engagement.

Figure 7. Plot of three-cluster solution of *Forgotten Island* players' behavioral engagement.

The largest group (cluster-2, green dots) held 1,141 players contributing a low number of decisions with good accuracy. The next largest group (cluster-0, blue triangles) held 214 players contributing at high quantity and with good accuracy. The smallest group (cluster-1, orange crosses) held 152 players who contributed a low number of decisions with poor accuracy.

Based on our cluster analysis results (Table 2), the largest groups of players in the two games (69% in *Happy Match*, 76% in *Forgotten Island*) had similar behavioral engagement characteristics. Players in this cluster completed a small number of decisions, showed reasonably good accuracy, but left after only making a small number of decisions. Both games also showed players who seemed highly attracted to the games, contributing a considerable number of decisions and with good accuracy (5% of players in *Happy Match* and 14% in *Forgotten Island*). *Happy Match* showed a relatively large group of players (26%) who contributed a small number of decisions with poor accuracy; *Forgotten Island* had a smaller group of such players (10%).

Our analysis also identified that 345 players tried both games, so we analyzed whether these players acted similarly or differently in the two games. The majority of the shared players belonged to cluster-2 (low quantity, good accuracy) in both games (197 players), but the rest had different cluster labels in each game. Ten players were highly engaged in *Happy Match* (cluster-0), and yet eight of these contributed only a few decisions in *Forgotten Island* (cluster-2). Sixty-one players were highly engaged in *Forgotten Island* (cluster-0), and yet 51 of these 61 players completed a low quantity of decisions (cluster-2) in *Happy Match*. These results further showed the overlapped players had an imbalanced interest towards either *Happy Match* or *Forgotten Island*, supporting that the two citizen science games attracted distinctive players.

4.2. Analysis #2: Content analysis of players' psychological engagement

We continued our exploration by reaching out to registered players in the *Citizen Sort* system to get their qualitative insights about their experience with *Happy Match* and *Forgotten Island*. We recruited participants to this second analysis by emailing a Qualtrics questionnaire link to all valid players in the *Citizen Sort* system. Responses were incentivized with a random drawing for a $10 Amazon gift card, and we received 76 responses, a 2% response rate that was low but still resulted in a usable set of qualitative survey data.

Among the 76 survey participants, five had already been filtered at the data screening stage of the cluster analysis (Analysis #1), and another five did not provide any responses to the open-ended questions. Therefore, our qualitative analysis was based on data from 66 survey participants. Thirty-two participants were players of *Happy Match* and 34 were players of *Forgotten Island*[5].

The thirty-two *Happy Match* survey participants were between the age of 21 and 67, and one participant chose not

Table 2. Three-cluster solutions of *Happy Match* and *Forgotten Island*.

Game	Cluster label	Number (%)	Total decision Mean (SD)	Accuracy Mean (SD)	Description	Survey sample	Total decision Mean (SD)	Accuracy Mean (SD)
HM	0	103 (5%)	654.08 (235.52)	0.76 (0.08)	High quantity, good accuracy	1	472 (n/a)	0.856 (n/a)
	1	612 (26%)	53.25 (45.62)	0.64 (0.10)	Low quantity, bad accuracy	4	30.75 (14.22)	0.67 (0.05)
	2	1610 (69%)	62.45 (57.28)	0.83 (0.06)	Low quantity, good accuracy	27	106.56 (91.40)	0.83 (0.05)
FI	0	214 (14%)	569.61 (184.67)	0.79 (0.09)	High quantity, good accuracy	11	622.73 (217.94)	0.81 (0.04)
	1	152 (10%)	107.86 (163.88)	0.48 (0.10)	Low quantity, bad accuracy	2	10 (8.49)	0.5 (0.00)
	2	1141 (76%)	55.57 (63.15)	0.82 (0.08)	Low quantity, good accuracy	21	63.81 (67.19)	0.85 (0.09)

Note: HM: *Happy Match*; FI: *Forgotten Island*, SD: standard deviation. Five survey respondents (four in HM, one in FI) were filtered at the data pre-processing stage of cluster analysis, and five survey respondents (four in HM, one in FI) did not provide any qualitative feedback.

to report the age information. Ten were men, 21 were women, and one chose not to report. The highest education of twenty-one participants was a graduate degree. Nine participants had an undergraduate college degree. One participant had a middle school education. Among the 32 participants, only nine considered themselves as gamers. The majority expressed interest in science ($n = 30$), nature-related activities ($n = 29$), participating in science activities ($n = 21$), and reading fictions ($n = 27$). On average, they spent approximately 4.9 hours (Min = 0, Max = 20, Median = 4, SD = 5.47) per week playing single-player games.

The thirty-four *Forgotten Island* survey participants were aged between 18 and 60. There was one participant chose not report the age information. Twelve were men, and 22 were women. Twenty of the 32 participants reported their highest level of education was graduate degree, and 12 had an undergraduate college degree. One participant reported a high school education, and one participant had a middle school education. Among the 34 participants, only fifteen considered themselves as gamers. The majority expressed interest in science ($n = 33$), nature-related activities ($n = 30$), participating in science activities ($n = 22$), and reading fictions ($n = 29$). The survey participants spent about 9.8 hours per week (Min = 0, Max = 70, Median = 7, SD = 13.64) playing single-player games.

Before analyzing the survey data, we mapped the survey participants' IDs to the dataset used in Analysis #1 in order to identify their cluster assignments. Table 2 above reported survey participants' cluster assignments in *Happy Match* and *Forgotten Island*, respectively, and the means and standard deviations of survey participants' total decisions and accuracy by cluster. The results supported that survey participants showed consistent behavioral engagement characteristics with their corresponding overall population clusters. It is notable that one participant responded to both our survey invitations. We checked the cluster label of this participant. Results of Analysis #1 showed that according to the participant's behavioral data in *Citizen Sort*, this participant was categorized into cluster-2 in *Happy Match* and yet cluster-0 in *Forgotten Island*, supporting that this player engaged differently in these two games.

Demographic information shows that our survey participants had good representation in terms of age and gender, but our sample is dominated by participants who were interested in science, likely a result of publicizing the games on various citizen-science websites over the past several years. Therefore, we should note this characteristic when interpreting the analysis results of the survey data.

We used content analysis methods introduced by Neuendorf (2017), adopting an inductive procedure to analyze player responses. We treated each player's response to each question as the unit of analysis. Two coders were trained to apply the open-coding procedure. These two coders independently developed codes, generating a draft coding schema based on the first ten survey responses. A third coder moderated the discussion to reach consensus on the meaning of codes. Additional codes were added during the analysis procedure that followed, and the coding schema was finalized when all coders agreed it reached saturation. The initial inter-coder reliability was 93.82% and reached 100% after several rounds of discussion.

This procedure resulted in two relevant categories of codes: (1) a category focused on elements of gameful systems called "design elements" and (2) a category focused on gameful experience called "psychological engagement." Each category contained a selection of unique codes based on ideas articulated by the survey participants. Codes were rated as either "positive" or "negative" based on the language used and the overall context of the feedback. For example, the quote, "I like that the classifications were integrated in a story," was rated as "positive" because of the language, "I like." The quote, "I stopped playing very soon, and it's mostly because I find moths extremely boring," was rated as "negative" because of the word "boring" and its association with the phrase "stopped playing." Codes were rated as negative or positive based on our coders' best understanding of each survey participant's own point of view. A code like "challenge" could be rated as negative if a participant suggested the game difficulty was too hard or too easy, making the game less fun to play. The "challenge" code could be rated as positive if a participant suggested that high or low difficulty led to greater enjoyment of the game. The majority of positive and negative evaluations had high initial inter-coder agreement. Disagreements were resolved through discussion.

Table 3 presents the frequency summary of "design elements" and "psychological engagement" codes. Players of both games provided more positive comments than negative comments (design elements: $N_{pos} = 106$, $N_{neg} = 45$; psychological engagement: $N_{pos} = 91$, $N_{neg} = 58$), showing generally favorable attitudes toward the two games.

Criticisms related to design elements focused mostly on usability, for example technical issues, difficulties with control of the games, and lack of direction. The design elements that lead to positive feedback for *Happy Match* and *Forgotten Island* were less consistent between the two games.

Table 3. Frequencies of design elements and psychological engagement.

Category	Codes	Positive (HM)	Positive (FI)	Positive (subtotal)	Negative (HM)	Negative (FI)	Negative (sub-total)
Design elements	Aesthetics	0	5	5	0	2	2
	Challenge	6	4	10	3	2	5
	Character	0	3	3	0	1	1
	Classification	6	7	13	2	2	4
	Control	0	1	1	3	5	8
	Direction	3	0	3	2	5	7
	Diversity	1	1	2	1	0	1
	Exploration	2	8	10	0	1	1
	Graphic	0	6	6	4	2	6
	Reward	2	3	5	0	0	0
	Science	15	20	35	0	1	1
	Story	0	13	13	0	0	0
	Technical issue	0	0	0	6	3	9
	Sub-total	35	71	106	21	24	45
Psychological engagement	Achievement	3	5	8	8	2	10
	Competence	0	1	1	5	1	6
	Enjoyment	7	10	17	4	2	6
	Interesting	6	13	19	10	11	21
	Learning	9	3	12	0	2	2
	Meaningfulness	12	12	24	3	0	3
	Personal interest	1	2	3	0	2	2
	Relatedness	3	5	8	8	2	10
	Sub-total	43	48	91	33	25	58

Note: Codes are listed in alphabetical order.

Happy Match and *Forgotten Island* players both positively noted the "science," "classification," "challenge," and "reward" aspects of the two games. However, *Forgotten Island* players more positively noted "story," "exploration," "graphic," "aesthetics," and "character," while *Happy Match* players more positively noted the "direction" of the game. This aligns with our understanding of *Forgotten Island* as a more gameful system than *Happy Match*.

In terms of psychological engagement, *Happy Match* and *Forgotten Island* players aligned closely in their reasons for liking the two games, noting the importance of "meaningfulness," "interesting," "enjoyment," and "learning." Negative mentions of *Happy Match* and *Forgotten Island* differed slightly by game. *Happy Match* players discussed their negative experiences in terms of "competence" (i.e., feeling like they were bad at the game), "relatedness," or their inability to achieve game goals. *Happy Match* and *Forgotten Island* players who mentioned the games negatively described lack of interest as one common factor.

4.3. Analysis #3: Three player types: Integration of cluster analysis and content analysis

Our third analysis developed connections between the quantitatively derived player clusters from analysis #1 and qualitatively derived content analysis insights from analysis #2. Using the email address provided by each participant in the study, we were able to link survey respondents to clusters. We then looked for patterns and trends in the qualitative data that might help to explain differences between the clusters. This process produced a more complete understanding of each player group. To aid in discussion of the groups we assigned each group a name based on its characteristics: "science gamers," "citizen scientists," and "dabblers."

4.3.1. Science gamers

We assigned the category name "science gamers" to players who exhibited a simultaneous interest in games and science. These players seemed to be enthusiasts who might especially gravitate toward gameful citizen science systems. In our data, they were characterized by (1) high individual contribution quantity, a measure that suggested substantial behavioral engagement in the games, (2) good accuracy, a measure that suggested focused and serious attention on the science aspects of the games, and (3) qualitative survey feedback that showed how these players were invested in a mix of play and science. Based on this feedback, we surmise that many of these participants would be interested in other kinds of games than citizen science games, and in other contexts could simply be referred to as "gamers."

The science gamer group was relatively small, comprising just 103 people (5% of players) for *Happy Match* and 214 people (14% of players) for *Forgotten Island*. Each individual player in this group made significant scientific contributions (a mean of 654.08 decisions for *Happy Match* players; a mean of 569.61 decisions for *Forgotten Island* players). This pattern is familiar: various researchers, for example Sauermann and Franzoni (2015) and Boakes et al. (2016), have shown that enthusiasts, while comprising only a small percentage of participants, tend to produce an outsized portion of the data and/or effort in most citizen science systems.

High frequency content analysis codes for this group included design elements like "science," "story," "challenge," and "rewards" as well as psychological engagement codes such as "interesting," "enjoyment," "achievement," and "meaningfulness." Table 4 shows selected responses for these codes. However, for this group of players, comments were all directed at *Forgotten Island*; our single *Happy Match* survey participant in this player group left very sparse qualitative feedback, making it difficult to interpret how science gamers react to the less gameful of our two systems.

Table 4. Selected quotes from *Forgotten Island* players characterized as "science gamers."

Category: Code	Times coded	Example quotes
D: Science	7	"The idea of doing science tasks and helping researchers in their daily work." "Knowing that I was helping out in the science community." "The scientific aspect of the game."
D: Story	7	"The story was pretty quirky and fun … this added a fun element." "To move the game forward [and] find out more about the story." "Definitely unlocking the plot."
D: Challenge	4	"Consistent challenges, the game didn't end right away." "The puzzle of the game." "Working out the challenges; still haven't beat that mean wheely robot!"
D: Rewards	3	"The in-game money that can be earned. Lesser the idea of helping researchers."
P: Interesting	6	"I thought the game was seriously cute." "The classifying interested me"
P: Enjoyment	5	"Honestly, I kind of forgot about the game. But I remember liking it, and at the time, thinking I should keep playing." "I loved the plant gardens. It was really fun filling them with interesting plants."
P: Achievement	5	"Filling the gardens with plants." "To move the game forward [and] find out more about the story"
P: Meaningfulness	4	"You don't necessarily have to have a PhD to be able to meaningfully contribute to the science community at large." "Knowing it was for a good reason."

Note: D: design elements; P: psychological engagement.

Given the disparity in survey response rates between *Happy Match* and *Forgotten Island* players for this player type, we suspect that our science gamers may, in fact, be more "gamer" than "scientist." *Forgotten Island* is a more gameful system than *Happy Match*, and in the end, our science gamer group appeared to be more enthusiastic about games that feel like true entertainment experiences (albeit with embedded scientific elements) than about science-focused games that feel like gamified tasks.

4.3.2. Citizen scientists

We assigned the category name, "citizen scientists" to players who especially focused on science, learning, meaningfulness, and interest or enjoyment derived from scientific engagement. These players contributed less individually but produced data with good accuracy. We assessed them as "citizen scientists" based on factors that included: (1) lower contribution quantity, suggesting a less substantial level of behavioral engagement with gameful systems, (2) good accuracy, suggesting these players take the science task seriously, and (3) qualitative survey feedback, which showed a marked interest in the scientific and educational aspects of *Forgotten Island* and *Happy Match* while deemphasizing most entertainment and play characteristics of the games.

The citizen scientist group is large, comprising 1,610 people (69% of players) for *Happy Match* and 1,141 people (76% of players) for *Forgotten Island*. Individual players in this group each made relatively few task decisions (a mean of 62.45 decisions for *Happy Match* players; a mean of 55.57 decisions for *Forgotten Island* players). Because of the number of participants in this group, it collectively generated the most data of the three groups.

Citizen scientists commented on key concepts in their open-ended survey responses. High frequency codes for this group included design elements such as "science," "challenge," "classification," and "graphics." In the category of psychological engagement, high frequency codes were "interesting," "meaningfulness," "enjoyment," "learning," and "achievement." Table 5 shows a selection of qualitative responses for these codes.

4.3.3. Dabblers

We adopted the name "dabbler" from Eveleigh et al. (Eveleigh et al., 2014), who used it to describe citizen science participants who engage briefly with projects, contributing modestly before moving on to new pursuits. Our third participant group exhibits much the same engagement pattern: these participants expressed curiosity about and interest in our two games (especially *Happy Match)* and explored the possibility of full participation, but ultimately did not engage fully or remain involved in the project for very long. Dabblers were characterized by (1) low quantity of contribution, suggesting modest behavioral engagement, (2) low accuracy, suggesting limited effort in the science task, and (3) qualitative comments that suggested less overall psychological engagement with the gameful and scientific aspects.

The dabbler group is of moderate size, comprising 612 people (26% of players) for *Happy Match* and 152 people (10% of players) for *Forgotten Island*. There are considerably more *Happy Match* dabblers than *Forgotten Island* dabblers in the *Citizen Sort* user base. *Happy Match* dabblers made about the same number of decisions (a mean of 53.25) as *Happy Match* citizen scientists while *Forgotten Island* dabblers made more decisions (a mean of 107.86) compared to their citizen scientist counterparts. Both *Happy Match* and *Forgotten Island* dabblers exhibited poor accuracy in their classification decisions (mean accuracy of 0.64 for *Happy Match* dabblers and 0.48 for *Forgotten Island* dabblers).

Dabblers played little before losing interest and ending their involvement with the games. However, the nature of the game appeared to make some difference in who initially showed interest and who remained. *Happy Match*, a less gameful system, attracted more dabbler players, while *Forgotten Island*, a more gameful system, had players that contributed more overall decisions. Despite these differences, we note that the majority of the data provided by dabblers in either game was not scientifically usable.

Table 5. Selected quotes from *Happy Match* and *Forgotten Island* players characterized as "citizen scientists."

Category: Code	Times coded	Game	Example quotes
D: Science	25	HM	"I wanted to find ways to engage younger people in science in a fun and interactive way where they could be part of the process."
		HM	"The scientific challenge of wading through data. Being a biologist myself, I can appreciate the decision to involve citizens in classification work."
		FI	"Scientific elements, feeling of contribution to science."
		FI	"That you could do real scientific work."
D: Challenge	10	HM	"Completing challenges."
		HM	"Some tasks were easier - counting a number or a simple relative comparison. Others were quite difficult to differentiate between."
		FI	"New tasks to complete"
D: Classification	10	HM	"I really liked being given ways to categorize moths I see."
		FI	"I really wanted to solve each classification."
		FI	"Learning about the classification process."
D: Graphic	10	HM	"I gave the first time (even if wrong) because the image did not clearly display the trait being categorized."
		FI	"interesting choices, graphics"
		FI	"The color palette and the vibrant feel of the game were pleasant and enjoyable to explore"
P: Interesting	31	HM	"I love insects, and learning more about them is never a chore."
		FI	"Very interesting idea! And a decent game with a huge educational value."
		FI	"The labyrinthine map was interesting."
P: Meaningfulness	20	HM	"The idea that I was doing something useful."
		HM	"I was glad to be able to contribute to scientific study. I had recently retired and was looking for a way to be productive."
		FI	"Honestly, I played it so I could help out. I wasn't playing it for the game itself. "
		FI	"Knowing that I was making an impact by helping play the game because it made me feel that playing the game mattered."
P: Enjoyment	18	HM	"It was a class assignment but it was a fun one and I appreciated the hard work and creativity that went in to it."
		FI	"It's so fun and eye-catching. It makes them think about citizen science in a whole new light!"
P: Learning	12	HM	"I learned how to look at different animals in a scientific, yet fun way."
		HM	"Interest in helping out as well as learning a skill and information about living creatures I can see in my own yard."
		FI	"Learning about the classification process."
		FI	"Very interesting idea! And a decent game with a huge educational value."
P: Achievement	12	HM	"Collecting of my Matches (Collection of photos)."
		FI	"Searching for things kept me interested in the game because I wanted to find it all."
		FI	"The plot and achievements helped to keep me interested in playing the game."

(*continued*)

Table 5. Continued.

Note: D: design elements; P: psychological engagement; HM: *Happy Match*; FI: *Forgotten Island*.

Players in the dabblers group commented sparsely in open-ended survey responses. This stands to reason, as these players probably were never engaged enough in the *Citizen Sort* system to respond to our survey or provide detailed feedback about the games. The few comments we did receive typically expressed several key ideas at once, and so were assigned multiple codes during content analysis. The high frequency design elements codes for dabblers included "classification," "science," "story," and "exploration," and the high frequency psychological engagement codes were "meaningfulness" and "interesting." Table 6 shows qualitative responses for this group with their respective codes.

5. Discussion

Our three groups of players reveal unique challenges in terms of recruitment and retention. In the following sections, we discuss possible strategies for engaging distinctive types of players to facilitate volunteer contribution in citizen science games.

Recruitment and retention are interrelated aspects of volunteer engagement in citizen science (Crall et al., 2017; Dickinson et al., 2012). Recruitment is when a prospective volunteer finds themselves interested enough to try some activity or task within a given project (Andow et al., 2016; Crall et al., 2017). Retention is a subsequent step, when a recruited volunteer finds the activity engaging enough to continue for some prolonged period of time thereafter (Andow et al., 2016; Crall et al., 2017). A recruited participant may be thought of as "auditioning" the citizen science game to see if it pleases; a retained participant is one whose engagement becomes routine. Our understanding of different player groups and their opinions of gameful design can lead to better informed design suggestions for recruiting and retaining science gamers, citizen scientists, and dabblers in gameful citizen science systems.

5.1. Recruiting and retaining science gamers

5.1.1. Science content

Science gamers are motivated by play, but also recognize and appreciate the eudemonic benefits of a citizen science game's scientific content. Our science gamer participants, for example, positively noted that, "the game explained that this is helping science," and reflected upon the value of,

Table 6. Selected quotes from *Happy Match* and *Forgotten Island* players characterized as "dabblers."

Category: Codes	Times coded	Game	Example quotes
D: Classification	5	HM	"Knowing that classifying these animals is somehow important."
		HM	"The game flow led to classification so naturally that's why I took part in the game."
		FI	"… I like that the classifications were integrated in a story."
		FI	"I'm not a big fan of classification tasks as I find them repetitive but having them included in a story was a great incentive to play and classify."
D: Science	4	HM	"The most important factor for me was knowing that I don't just waste my time, but playing the game is a helpful contribution to science. That was actually the only real reason for me to play."
		FI	"Really great effort in integrating citizen science in a gaming environment."
D: Story	2	FI	"I'm not a big fan of classification tasks as I find them repetitive but having them included in a story was a great incentive to play and classify."
		FI	"… I like that the classifications were integrated in a story."
D: Exploration	2	HM	"The game flow led to classification so naturally that's why I took part in the game."
		FI	"I really liked that it's an adventure game."
P: Meaningfulness	3	HM	"The most important factor for me was knowing that I don't just waste my time, but playing the game is a helpful contribution to science. That was actually the only real reason for me to play."
		HM	"Knowing that classifying these animals is somehow important."
		FI	"Really great effort in integrating citizen science in a gaming environment."
P: Interesting	3	HM	"I stopped playing very soon, and it's mostly because I find moths extremely boring."
		FI	"I've played quite a few citizen science games and this is the most original one."

Note: D: design elements; P: psychological engagement; HM: *Happy Match*; FI: *Forgotten Island*.

"knowing it was for a good reason." Though it may be tempting for a game designer to think of science content as a bothersome distraction for gamers, these findings clearly suggest otherwise.

Citizen science game designers who hope to recruit science gamers should therefore make sure that promotional materials for the game highlight, rather than downplay, the game's scientific importance. Advertisements and announcements may frame game play as an altruistic activity, an opportunity to help scientists, or an opportunity to engage in scientific work like a real scientist. Balancing promotional material to emphasize science and play together will help to recruit players with the right mix of interests for a citizen science game, which may lead to more recruited players overall.

To retain players, however, designers should also take care to ensure that the scientific content of the game does, indeed, integrate well with other aspects of play. Science gamers are, after all, *gamers*. Motivated though they may be by the eudemonic benefits of a game's science content, these players also seek hedonic benefits: enjoyment, fun, excitement, intrigue, etc. To convert curious recruits into retained players, designers must provide a game that effectively balances science content and play.

One way to do this may be to draw upon the notion of diegesis (Lane & Prestopnik, 2017; Prestopnik & Tang, 2015), turning seemingly disconnected science tasks into embedded, natural, and justified components of the game world. Diegetic elements of a game belong to the world of the game, for example the player character, non-player characters, locations, vehicles, etc. Non-diegetic elements can enhance the experience, but are not part of the world of the game, for example the game's graphical user interface, which might be used to manipulate an inventory, adjust settings, or modify the player avatar, but is not actually seen by characters in the game and is not a part of the game world (Stam et al., 1992). Designers who make science content feel diegetic to the overall experience may find that science gamers are more likely to find both scientific and playful elements fulfilling in both eudemonic and hedonic ways.

5.1.2. Story as a diegetic tool

Human beings have long been motivated and entranced by compelling situations, interesting characters, and well-crafted narratives, and science gamers who played *Forgotten Island* frequently commented on the importance of story as a motivating and intriguing element of play. Entertainment video games often use stories and fantasy as tools for motivating play (e.g., Costikyan, 2013; Garris et al., 2002; Malone, 1982; Malone & Lepper, 1987; Prensky, 2005). Crafting an engaging story can be difficult—more art than science—but feedback from our science gamer group suggests that story can be a key component of a gameful experience, even in a citizen science context.

To recruit science gamers, promise a compelling narrative that intertwines real-world science with narrative ingredients such as conflict, character development, and world-building. This can be teased through promotional material like story summaries, game art, "back of the box" descriptions, and the like. To retain recruited science gamers, pay off the promised story by following well-established narrative rules, just as any screenwriter or entertainment game designer would strive to do. Recognize that games are a mature art form, and science gamers will be sophisticated enough to demand a professional approach to storytelling in the games they play, including citizen science games.

5.1.3. Game genre and mechanics

One way to help science gamers to know more about the game is to leverage the power of a known game genre.

Gamers are familiar with many different genres, for example real-time strategy (RTS), role-playing games (RPG), first-person shooters (FPS), action platformers, puzzle platformers, point-and-click adventures, etc. Typically, players gravitate to just a few of these genres and look for new games to play within the genres that they enjoy most.

Designers may be able to do a better job recruiting and retaining science gamers by focusing on specific, well-understood game genres as a starting point for design. Designers can pattern the mechanics of their game based on other successful games in the genre, increasing the likelihood that the mechanics, aesthetics, and—especially—dynamics (Hunicke et al., 2004) of the game will engage players as intended. In our study, players noted the importance of rewards and challenges in our two games. Choosing a specific game genre can give designers a template for proven reward and challenge mechanics, reducing the chance that the game will struggle to capture a player base.

In a sense, this is advice for designers to forget, if only temporarily, that they are crafting something unique and unusual: a citizen science game. Instead, designers should focus on established design patterns from the world of entertainment gaming. Prospective players will more easily be able to decide whether the game genre looks like something that they are familiar with and might enjoy. Players who are recruited in this way may be more likely to accept the addition of the citizen science content, becoming retained players and producing correspondingly more and better data.

5.1.4. The power of aesthetics

Some of our study participants noted the importance of visual design and aesthetics to the overall play experience and the corresponding sense of fun that our games engendered. From a standpoint of recruitment, our two games were relatively successful: the games *looked* fun, and so many players signed up to try them. However, we also noted in our data that many players, our "dabblers," tried our games only briefly, suggesting that aesthetics alone were not fully successful at retaining players over longer periods of time.

To retain science gamers more successfully, the promise made by the aesthetics of the game—the professional-looking graphics, the cute robots, the intriguing world, the unique locations—should be complemented by the mechanics and dynamics of play (Hunicke et al., 2004). Rogers (2010), notes that, "there's nothing worse than an empty level you just walk through," arguing that the beautiful aesthetics of a well-crafted game world and the exploration thereof are, by themselves, not enough to sustain players for very long. Aesthetics can be used to recruit, but they must be partnered with other elements of a gameful system to retain players for any length of time.

Drawing upon Norman's (2004a, 2004b) three-part theory of aesthetic appreciation, which is divided into immediate, "visceral" reactions, "behavioral" appreciation through use, and "reflective" appreciation through contextualization and reflection, we argue that the aesthetics of a game can serve a visceral role during recruitment, but take on behavioral and reflective dimensions later during play. The mechanics, story, and dynamics of play are mostly appreciated behaviorally and reflectively, and so these become highly important additions to the experience once recruitment is achieved and retention begins. Table 7 summarizes the design recommendations for recruiting and retaining science gamers.

5.2. Recruiting and retaining citizen scientists

The interests of Citizen Scientist players overlap with—but are distinct from—those of science gamers. Accordingly, we suggest alternative approaches for successfully recruiting and retaining this kind of player.

5.2.1. Science engagement and learning opportunities

Our citizen scientist players were highly motivated by the opportunities that our games presented for participating in scientific inquiry and learning new things. For example, citizen scientist participants noted: "I enjoyed the idea I was helping with scientific research," "I wanted to contribute to the scientific community," "… learning a skill and information about living creatures I can see in my own yard," and, "… a decent game with a huge educational value."

To successfully recruit citizen scientists, designers should understand that play will likely be a secondary motivation for this kind of player. In recruitment materials, emphasis should be directed at the ways the game will allow players to engage with real-world scientific inquiry, partner with real scientists, and work altruistically to discover new things and better understand the world. Since citizen scientist players are usually not trained scientists, recruitment materials should also emphasize the learning opportunities of the game. These can include new knowledge about the game's domain of inquiry, for example, taxonomic classification and moths in the case of *Happy Match* and *Forgotten Island*. It is not to be overlooked, however, that learning opportunities might equally focus on the broader context of scientific inquiry, the scientific method, and the ways that professional scientists collect data, analyze it, and disseminate their findings to the world.

To retain citizen scientists long term, games should be designed around features that foreground the scientific and learning activities in the game. Many game designers, influenced by Csikszentmihalyi's work on optimal experience (Csikszentmihalyi, 1990), are familiar with the need to balance challenge and player ability in a game. In a gameful experience directed toward citizen scientists, this balance might be achieved by designing increasingly demanding scientific challenges and activities into the game.

5.2.2. A community of inquiry

Designers should look for ways to connect citizen science players to the wider community of citizen scientists, and perhaps to the professional scientists involved in the project as well. Some citizen science projects, for example the *Zooniverse* project, have successfully transformed citizen scientist participants into collaborators and co-authors, a true

Table 7. Recommendations for recruiting and retaining "science gamers."

Science gamers		
Recruitment recommendations		Retention recommendations
Science content should be advertised as an aspect of play	►	Science content should be integral to game play
Promise a compelling narrative, especially if developing in a story-friendly game genre	►	Pay off the promise by following storytelling rules: structure, character development, twists, turns, conflict, setbacks etc.
Design around a recognizable game genre (e.g., point-and-click adventure, RPG, FPS, MMO, action platformer, puzzle game, etc.) so that prospective players will easily grasp the game's promised challenge and reward systems	►	Pay off the promised genre and its associated rewards and challenges. Game rewards are most meaningful when they feel earned, so don't be afraid to make use of genre-appropriate challenges and penalties like lost lives, lost progress, difficult puzzles, etc.
In a visceral, attention-grabbing way, aesthetics should be intriguing and look/sound/feel like an entertainment game	►	In a more reflective and behavioral way, mechanics/dynamics should maintain interest and continue to feel like an entertainment game over the long-term

culmination of some of these participants' ambitions to become involved in scientific inquiry.

In a game like *Happy Match*, players who so aspire could be given new tools or features that help them collaborate on more meaningful problems. For example, instead of classifying moths and producing data for later use by professional scientists, this game could have an advanced mode where players conduct analysis on the collected data for themselves, perhaps mapping classified moths to geographical data and time of year. The professional scientists involved in such a project might submit research questions to groups of advanced players, seeking a more sophisticated involvement from participants who have proved themselves on simpler tasks.

5.2.3. Balancing gamefulness vs. science

While science gamers may be highly motivated by the playful aesthetics and mechanics of a gameful system, citizen scientists, with their focus on scientific inquiry and learning, may find more playful elements of the experience unnecessary, distracting, or even unwelcome. One citizen scientist participant in our study suggested, "Honestly, I played it *[Forgotten Island]* so I could help out. I wasn't playing it for the game itself. The game was kind of just an added "meh" bonus, like a side of boiled carrots. Just there, not really helping or hurting anything."

Game designers should keep comments like this in mind when designing for citizen scientists as opposed to science gamers. In both player groups, there is a balance to be found between the scientific content of the gameful system vs. entertaining, playful elements. For citizen scientists, psychological and behavioral engagement favor eudemonic science activities more than hedonic, playful ones.

Designers who attempt to recruit and retain citizen scientist players should develop the game's mechanics so that they underscore scientific and learning essentials of the game. They should also avoid including too many extraneous mechanics, complex story elements, or in-depth world building that could be unwelcome to this kind of player. Note, however, that our citizen scientist players did appreciate some gameful aspects of both *Happy Match* and *Forgotten Island*. For example, players in this group noted that, "The color palette and the vibrant feel of the game were pleasant and enjoyable to explore," and "The labyrinthine map was interesting," and, "It's so fun and eye-catching. It makes them think about citizen science in a whole new light!" The word "balance" is appropriate when thinking about what kinds of game elements to include or exclude; even citizen science gamers can appreciate the hedonic attributes of citizen science games. Table 8 summarizes the design recommendations for recruiting and retaining citizen scientists.

5.3. Converting dabblers (and making use of their data)

Our third type of player, dabblers, found *Happy Match* and *Forgotten Island* to be interesting at first, but quickly left after contributing little and with poor accuracy. That is, dabblers were successfully recruited, but unsuccessfully retained. We nonetheless consider dabblers to be an important player type for citizen science game designers to keep in mind. These are players who exhibit psychological and behavioral engagement to some degree. Adherence to our recommendations above might turn some of these players into long term science gamers or citizen scientists. Design improvements, for example a more polished game experience, a better-suited game genre, more involving community or social features, more task variety, or direct interaction with or impact upon the scientific community, could address their concerns.

Not all dabblers can be persuaded to become fully engaged in a citizen science project. Our dabbler players noted some reasons that were beyond our control for discontinuing play, for example: "I stopped playing very soon, and it's mostly because I find moths extremely boring," "Continuing to play wasn't a top priority for me at the time after I first played it," "For poorer health reasons than anything," and "busy."

It is worthwhile to consider how the effort put in by dabbler players can be valued and used, no matter how long their engagement with the system lasts. Previous study of *Happy Match* and *Forgotten Island* (see: Prestopnik et al., 2014, 2017) showed how data provided by some low-contribution players can nonetheless be of good quality and

Table 8. Summary recommendations for recruiting and retaining "citizen scientists."

Citizen scientists	
Recruitment recommendations	Retention recommendations
Emphasize science engagement; show how citizen scientists will be helping professional scientists, improving the world, etc.	► Pay off altruism and learning together:
Promise learning opportunities to prospective players (learning could be about domain knowledge or about the scientific process itself)	► as players advance in their knowledge and skills, increase challenge by engaging them in new aspects of the project, for example data analysis, publication, or scientific discovery
Use social features to connect citizen scientists to each other and a broader community of inquiry	► Break down social barriers between citizen scientists and professionals; let players feel like part of the "in" crowd and make real contributions
Games can look/sound/feel more like a tool for science (but it's okay for these to be playful and fun as long as they don't distract)	► Avoid letting gamefulness interfere with science engagement

useful. One possible strategy, if players are expected to engage with a system only briefly, might be to emphasize recruitment over retention, bringing large numbers of players to a project to generate a small amount of data per player (but large amounts of data overall). Designers should proceed with caution in such cases; Bogost (2011), for example, critiques egregious examples of this type of approach as "exploitationware," with good reason. However, Eveleigh et al. (2014) argue that, "Supporting dabbling behavior in citizen science can help to widen the impact of the underlying research, by raising awareness of scientific research problems and promoting scientific working methods and values."

Designers should take care that their system allows for careful curation of the data generated by dabbler players. In our project, dabblers produced data of poor quality in aggregate, but some produced very usable data individually. Both *Happy Match* and *Forgotten Island* included instrumentation and gold standard comparison data that helped us to evaluate the quality of data generated by an individual player so as to accept or reject it as the case warranted. Without this, we would not have been able to use any of the information generated by dabblers; with it, many dabblers did contribute meaningfully to our project.

5.4. Limitations

We note several limitations of this research. First, our study focused on two citizen science games that were developed by the research team specifically to investigate the impact of game design in the context of scientific inquiry. The games are specialized artifacts with many differences in terms of aesthetics, mechanics, story, and dynamics, not to mention the gameful experiences that result from them during play. Being designed by the same development team, however, *Happy Match* and *Forgotten Island* also have many commonalities. They share the same scientific task and context, and though they differ in the game elements they include, they have some common aesthetic and experiential sensibilities, which could influence our analysis and conclusions.

Second, this study is exploratory in nature, is based on just two example games, and draws upon a relatively narrow set of evaluation metrics focused on behavioral and psychological engagement, integrating data from the system and the open-ended survey questions. We asked few questions in this study about our players' broader motivations, socioeconomic circumstances, demographics, and value systems, all of which might significantly impact how and if an individual would play certain kinds of citizen science games. In addition, as with all citizen science projects, our participants are unlikely to be a true reflection of the wider world. Relatively few people, compared to the world at large, volunteer to participate in citizen science initiatives, and some demographics are better represented than others, possibly because of availability of time, access to resources, or awareness that participation is possible (Pateman et al., 2021).

As a result, we are limited to a narrow understanding of our three groups based on their measurable engagement and the open-ended insights they cared to provide; in future work, we hope to expand our understanding of these groups, exploring other motivational considerations and looking for commonalities in the ways players might solve problems, engage with story, or interact with the environment of a gameful citizen science system. Nonetheless, we consider that this current study produced actionable and beneficial design recommendations. By triangulating quantitative and qualitative data focused on engagement specifically, we give designers and researchers an insight into the ways that different approaches to game design have influences on player engagement in a real-world context. A future study on individual player differences and motivations may expand our analysis of the dynamics between various participants and citizen science games.

Our interpretation of various qualitative insights was limited by the small response size of our survey and specific characteristics of our participants (for example players of *Happy Match* played for fewer hours on average than players of *Forgotten Island*), as well as the amount of time that passed between when we collected our survey data and when players had last played the game—in some cases several years. Not all survey respondents provided sufficient qualitative information for us to fully understand their thoughts or opinions, possibly because for some, their memory for the games had faded over time. This made it challenging to develop truly robust connections between quantitative measurements and qualitative data. Additionally, most survey participants claimed an intrinsic interest in science, but only a small portion considered themselves as gamers. This imbalanced interest in games and science raises questions about our players' initial motivation for playing citizen science games, and this is especially true for certain player types, such as the few science gamers who played *Happy Match* or dabblers who tried and then abandoned *Forgotten Island*.

Game scholars continue to identify new opportunities for using games to educate and enhance knowledge building (Schrier, 2019), and citizen science researchers have increasingly begun to recognize issues associated with research misconduct (Rasmussen, 2019) and participant access. We anticipate further exploration of these questions and more. Such research will benefit from an expanded set of gameful systems, gameful experiences, players, and scientific contexts to analyze. Only by aggregating data from many different citizen science games can we hope to further elaborate on our understanding of the term "citizen science game players" and form new design recommendations to enhance player engagement in citizen science games.

6. Conclusion

Our study contributes to extant literature on citizen science by identifying a three-group typology of citizen science players, based on triangulated analysis of data from actual players in two citizen science games. We explored and compared the impacts of less gameful (i.e., *Happy Match*) and more gameful (i.e., *Forgotten Island*) systems on these players' behavioral engagement and psychological engagement in the citizen science context.

Previous research on player types, such as Bartle's typology of game players and the Hexad framework, provided some foundation to classify player types in games. Our research extends earlier theorizations by using data to focus on player types in a specific context: citizen science games. Our analysis generated three player types, which we named as "science gamers," "citizen scientists," and "dabblers" based on their distinctive psychological and behavioral engagement patterns with relation to both play and task. Science gamers were players who contributed a high quantity of data with good accuracy while simultaneously showing high engagement with the science and play aspects of citizen science games. Citizen scientists were players who contributed a reduced quantity of data, but with good accuracy; this group of players accounted for the majority of players in both games, and their qualitative insights showed that they placed a greater emphasis on scientific aspects of the games (eudemonic elements) than on entertainment (hedonic elements). Dabblers, our final player type, were characterized by low contribution quantity and poor accuracy in aggregate. They showed a relatively low level of engagement with scientific and play aspects of both games, though their initial enthusiasm and good quality data contributed by certain individual players suggests that some dabblers could be converted into active, engaged participants with the right kind of gameful system design or recruitment/retention effort.

Our results confirmed that science gamers, citizen scientists, and dabblers show different preferences about the work and play embedded in citizen science games. Though participants in each of these three groups exhibited a generally favorable attitude toward the two citizen science games, their specific comments on design elements and their own gameful experience reflected very different reasons for participating. With this in mind, we drew upon our understanding of game design and player types to suggest various design considerations that could be important for researchers and designers when they attempt to recruit and retain different kinds of players to gameful systems in the citizen science context.

Notes

1. https://eyewire.org
2. https://fold.it
3. http://www.citizensort.org (Note: the citizen sort system is no longer actively recruiting players for all games)
4. When players registered in the Citizen Sort system, some players chose not to report their accurate ages, so we report both the mean and median of players' ages.
5. One participant responded to both surveys because this participant played both games. Since our data analysis results were reported by game, we treated this participant's answers to each survey as separate responses in the following analysis and report.

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