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Making knowledge through the citizen science game

Ladan Cockshut, Games, Art, and Design, School of Computing, Teesside University
& Junior Research Fellow, Hatfield College, Durham University

Abstract

Citizen science is not new. Nor are videogames. When put together, however, these elements comprise a novel and emerging area of work that is transforming not only research outputs but also the ways in which play can *make knowledge*. This chapter explores the recent rise in the *citizen science game*, or crowdsourced games with a purpose, that has begun to revolutionise research approaches in areas of the physical and environmental sciences. It overviews the ways in which this dynamic new relationship—between scientist and gamer—is transforming the ways in which scientific research can take place. It also interrogates the creative *making* that is happening as a result of this dynamic relationship between scientist and gamer and what paradigmatic shifts citizen science games signal for the future of play and games on the one hand, and for the nature of scientific research on the other.

Keywords: citizen science, games, gamer, scientist, science, research, making knowledge

1. Introduction

In September 2011, scientists published news of a breakthrough. After global effort comprising over a decade of trying—and failing—to generate a model for an enzyme-sniping protein critical in the reproduction of the AIDS virus, they had finally—after just three weeks of trying—been able to 'generate models of sufficient quality for successful molecular replacement and subsequent structure determination. The refined structure provides new insights for the design of antiretroviral drugs' (Khitab *et al*, 2011: 1175) in the treatment of the virus, they concluded. Whilst this was a welcome step toward additional treatments and a potential cure for HIV, the process by which this discovery was made was even more remarkable. Scientists had largely turned the work of protein folding (the process by which they would posit and generate models for structural determination) over to amateurs. Rather than bringing dozens of world class professional researchers on board to solve this problem, the team (based at the Center for Game Science at the University of Washington) developed a citizen science game called *Foldit* and invited puzzle solving gamers to try their hand at positing folded proteins. The game itself had a leader board and gamers could work in teams to solve the protein folding puzzles. And most importantly it tapped into areas of human-based computational skill that computer-based algorithms have yet to replicate or improve on: intuition, visual cognition, and pattern-matching skills. As the authors noted, 'The critical role of Foldit players in the solution … shows the power of online games to channel human intuition and three-dimensional pattern-matching skills to solve challenging scientific problems.' (Khitab *et al*, 2011: 1177) Utilising a novel co-productive creative process designed around a citizen science game, this innovative approach to making knowledge enabled a significant step forward in an important area of scientific research. And in the years following this breakthrough, a small but increasing number of citizen science gaming approaches are being used in physical sciences research (Cooper *et al*, 2010; Trueille and Das, 2014, Rallapalli *et al*, 2015) by enlisting large numbers of volunteers to analyse and produce data in an immersive and creative gameplay environment.

Citizen science itself is not new, but its gamification and digitisation is. Recent years have seen a noticeable upsurge in new forms of citizen science through the provision of shared data collection or analysis via digitisation (i.e. Zooniverse), collective knowledge creation within the online space (Wikipedia, Encyclopedia of Life) and now the design of citizen science games[1]: videogames created by scientists to engage and enlist the public (gamers) in scientific research and analysis (i.e. FoldIt or EteRNA). These games provide a unique way of making knowledge between these two participants: the scientist and gamer.

For almost as long as we've had digital games, there has been controversy about them. The pattern and emergence of these controversies is well reflected in the themes and trends in academic research and literature around the topic of digital games. While first seen as a technical marvel, or even a technique to verify or test computing, computer or video games then went largely ignored by academia until the late 1970s, or at least until their cultural popularity gained attention in the media. Suddenly, videogames were now raising questions around their impact on social interaction and addiction, on their causal relationship to violence or anti-social behaviours and norms. Their widespread popularity appeared to signal a shift in popular culture and generate new forms of playful engagement that early games and play theorists like Johan Huizinga and Roger Caillois could not have imagined when they wrote in the 1930s and 50s. (Huizinga, 1938; Caillois, 1958) And as with many new things that are taken to by a noticeable part of society, it raises questions and expands possibilities.

I was contacted by a fellow games researcher in late 2012, asking me if I'd seen these 'citizen science games' that were starting to pop up. At that point I'd only heard of *Foldit* and the sudden success its gamers had had in folding that AIDS-related protein. (Khitab *et al*, 2011) As a researcher who'd long been interested in studying the widening scope and capacity of games in society, this felt like exciting news. Here were scientists, faced with a real challenge, one that could make a difference in studying and curing a devastating disease, and some unlikely allies had 'saved the day'. It felt like the conclusion of a far-fetched

[1] For the purposes of this chapter, the games discussed will be referred to as 'citizen science games' rather than 'games with a purpose', which is another term sometimes used to refer to these types of crowdsourced games.

natural disaster film where the unlikely hero swooped in at the eleventh hour and rescued the planet. These games, and their active facilitation of dialogue and creative making between what appear to be two unlikely allies, seem to demonstrate even more ways in which videogames continue to evolve.

It seems fitting, then, that Brendan Koerner, in his *Wired* article about the citizen science game *EteRNA* had described them as a 'science crowdsourcing tool disguised as entertainment' (2012). They are designed with entertainment, competition, and reward at their core to engage a widening group of participants and capitalize on their particular skillset: that of puzzle solving. These citizen science game pioneers have opted to shift the focus from eliciting the public's support using science alone to building in elements of gamification (Hamari, Koivisto, & Sarsa, 2014) to expand and sustain wider engagement and input. This chapter explores a selection of these games and considers the impact of drawing together what is often viewed as one the most laudable of pursuits of our modern society, scientific research and analysis, with what is often seen as one of its more contentious elements, the videogame. As with the commercially oriented videogame, communities and supporters are forming around these games and signalling a new dynamic interaction between the professional and amateur, appearing to capitalise and hone in on specific skillsets of each group. This chapter, however, interrogates the opportunities and potential challenges that this relationship presents and considers questions around the sustaining and designing these games going forward. Do games become something else when they can *make knowledge*? Are they reshaping the landscape of how scientific knowledge is produced and who should and can be involved? Or are they simply symptomatic of our current digital era with its predilection to 'gamify' everything?

2.1 Background: contextualizing the digital game

Why do we play games? Is it to entertain ourselves? To distract? To learn? To challenge? Play and games are concepts which seem interwoven into an associational relationship (called 'a bounded utility' by games theorist Alexander Galloway [2006: 19]). Scholarly approaches to play and games across multiple disciplines have been predominantly situated within studies of leisure pursuits; animal behaviour; or childhood development. (Caillois, 1958; Juul, 1938; Smith, 1984; Sutton-Smith, 1986, 1997). In addition, within the humanities, the definition of play and games has typically been regarded through its meaning and utilization within *culture*. (Huizinga, 1938) Play and games have also been considered in terms of a kind of process of ordering or categorization of rules and structure, particularly when attempting to define or contextualize it. (Caillois, 1958) Probably largely due to their pervasive nature, it is not surprising that play and games have been approached from different disciplines in different ways. This has been highlighted by some researchers, suggesting that making an over-arching theory about play is difficult. According at least one play researcher, Brian Sutton-Smith, 'when it comes to making theoretical statements about what play is, we fall into silliness' (1986: 1). He viewed that problems in conceptualising play come partly 'because there are multiple kinds of play and multiple kinds of players' (Sutton-Smith, 1986: 6). Sutton-Smith attributes the complexity of defining play to its variability. He posits that play is a 'facsimilization of the struggle for survival as this is broadly rendered by Darwin' (1986: 231). If, in fact, play represents the fundamental human drive to survive and all games 'act out' that struggle, then play is more than just a trivial distraction or leisure pursuit. Play is not necessarily a tidy experience that always has a beginning, middle and end—there is dysfunction and obligation, there is the 'work' of play, there is the failure in play.

Games theorist Jesper Juul draws on seven distinct (though not uncomplimentary) definitions of a game, all suggested by different academics (2005), before suggesting a definition of his own,

> a game is a rule-based system with a variable and quantifiable outcome, where different outcomes are assigned different values, the player exerts effort in order to influence the outcome, the player feels emotionally attached to the outcome, and the consequences of the activity are negotiable (2005: 36)

The usefulness of Juul's definition is that it strips away any contemporary or historical factors that might limit an understanding of games whilst also considering the core elements of what makes a game works and how the nature of play (or the player) fits within that. But games and play are about more than simply rules or outcomes. They are also about action. The action or physical process of play connects the rules and outcomes of play with the components of such activity, such as through the digital interface, or the game pieces, by which the player accesses and navigates the game. As Espen Aarseth explains,

> Games are both object and process; they can't be read as texts or listened to as music, they must be played. Playing is integral, not coincidental like the appreciative reader or listener. The creative involvement is a necessary ingredient in the uses of games (Aarseth, 2001: 1).

This making of play—the action of play—demands not only a 'creative involvement' on the part of the player, but helps explain why games and play are so entwined with each other. Unlike, as Aarseth suggests, the appreciative music listener who can enjoy a great piece of music without actually having participated in its production, the player has an active role in *making* the game happen.

With regards ways in which academic research has approached its study of the videogame, this has often been in relation to its place within and impact on society. Some of the earliest studies into videogames were interested in the health and psychological impacts of games on gamers. Research has looked at, in particular, the links between aggressive behaviour and violent games (for example, Griffiths, 1998; Ferguson, 2010); addiction or pathological games use (King *et al*, 2009; Sim *et al*, 2012); the impact of digital games on childhood and adolescence (Olson, 2010; Fromme, 2011); and the gendered nature of games (Subrahmanyam & Greenfield, 1994). Some studies, in response to some research, have engaged in a debate around whether there can be a valid categorization of gaming as either addictive or aggression-inducing in nature (Wood, 2008; Ferguson and Dyck, 2012), suggesting that while academic research has been interested in discovering a link between games and their adverse impacts, successfully making a link (or disproving one) remains undetermined.

In addition to research into the psychological or sociological impacts of gaming, the study into its health impacts has been more varied in scope, with some research focused on the potential negative impacts on health such as its causal impact on obesity or attention deficit hyperactivity disorder (ADHD) (Burke *et al*, 2006; Chan and Rabonowitz, 2006) while others have identified the benefits of gaming as a pain management tool (Raudenbusch, 2003); in cognitive development or improvement among children or older adults (Basak *et al*, 2008; Whitlock *et al*, 2012); and as a benefit for individuals with neuropsychiatric disorders such as autism (Tanaka *et al*, 2010).

Studies into videogames have also expanded to look at the nature of the games themselves (Aarseth, 2001; Juul, 2005); games design (Salen and Zimmermann, 2003); the narrative (Jørgensen, 2010); and the relationship between the virtual of the 'gaming world and the real world' (Galloway, 2004: 1). Another way that interested scholars have reflected on the digital game is from the perspective of the interface (Galloway, 2006, 2012) and the structure (from the devices through to the in-game) of the game (Ash, 2009) and its related embodied actions. What the digital game was and how it could be studied and defined became a foremost interest, as these scholars began to place their work in what was being referred to as *(computer) games studies*, an interdisciplinary field devoted to the digital game and its layers of meaning in action (Aarseth, 2001) and above their own individual disciplines.

New areas of research into the serious or educational game, including more recently the citizen science game, has brought to the fore an interest in and attention to the use of gaming concepts and ideas in a non-traditional, non-commercially oriented environments. Research into educational games has explored games developed to support education (often called 'serious games') for use in the classroom (Prensky, 2001, 2005); on the ways that existing forms of gamic action can support educational agendas to teach a particular subject or skills (Griffiths, 2002; Lim, 2009) or as an educational tool, particularly for students with disabilities (Khandaker, 2009); and it has also researched any links between gaming (particularly excessive gaming) and poor academic performance (Jaruratanasirikul *et al*, 2009). This has also led to recent attention around taking core game design ideas and related outcomes and applying them to other environments such as education, health or business through a process referred to as *gamification.* (Reiners, T and Wood, LC, 2014; Surendeleg, G. *et al.*, 2014) Gamification is defined as 'a process of enhancing services with (motivational) affordances in order to invoke gameful experiences and further behavioural outcomes' (Hamari, J., Koivisto, J. & Sarsa, H., 2014: 3026). Gamification is used primarily in contexts seen as being beyond actual conventional games. Hamari *et al* frame gamification as being a 'next generation method for marketing and customer engagement' (2014: 3025) and Deterding *et al* (2011) have described it as a way to encourage positive user engagement in products and services. Gamification techniques rely predominantly on positive user feedback and tangible game-like goals (achievements, leaderboards, quests), and while there has been a growing interest in this approach within business, educational, and third sector areas, its effectiveness remains under-studied (Hamari *et al*, 2014).

All of these diverse areas of research and engagement, across disciplinary and thematic lines, suggest that the elements of play and games (and their impact) are finding their way into new environments and raising possibilities around their benefits, challenges, and application beyond their traditional constructs. It is becoming clear that games and play are not merely a developmental construct of the young, or a commercial venture It would seem, then, to cause little surprise when these principles of play and games may be finding their way into the provision of academic research practices themselves. And as games are, at their core, an action-based medium, it seems a well-suited, malleable practice that allows for further modalities of engagement beyond the traditional or conventional.

2.2 Background: Making citizen science into games

A few years ago, I informally asked a few science colleagues what they felt was limiting their discipline—what was needed to support the next great 'leap forward' in their fields of research. Invariably a number of them said that greater computational power or innovations were required. Scientific research, one explained, requires increasingly sophisticated algorithmic innovations to effectively manage the increasingly massive data outputs that need to be analysed and handled. There are areas of research where human-based computing is acknowledged as still being ahead of any computational algorithm currently in place. (Cooper *et al*, 2010; Eiben *et al*, 2012) And for scientists working in these areas, they acknowledge that handling the analysis needs as a result of this era of big data requires innovating a 'new approach to solving computationally-limited scientific problems' (Cooper *et al*, 2010: 756). And for some researchers and research projects, using a crowdsourced approach to scientific research which draws on an engaged public has proved an effective tool. (Cooper *et al*, 2010; Treuille and Das, 2014)

The professional, modern scientist as we know it today first emerged in the early nineteenth century from the Scientific Revolution which began in the 16th century, and with it came the origins of the first doctorate degrees in the sciences. Even the term *scientist* in the English language is relatively new, having only been coined in the 19th century by William Whewell. (Ross, 1962) The doctorate in science was first established in Germany in the early 1800s and expanded to other nations into the late 19th and early 20th century. (Rüegg, 2004) Before this time, scientific research was largely conducted by individuals more typically referred to as natural philosophers, or scholars who had a philosophical interest in the natural or physical world. It these earlier days, the scholar who reflected on scientific ideas, might also be considered a philosopher and in some cases had taken orders within the Church. An early scientist's qualification or predisposition to explore science was not necessarily related to a particular scientific qualification at university. According to modern standards, it could be argued that their work was, to a large extent, what might now be viewed as amateur.

Modern approaches to scientific research typically expect that it is performed by the trained, highly qualified professional. It has never fully abandoned the role of the amateur, or citizen, however. As far back as the eighteenth century, volunteers have been sought on a large scale to submit or collect scientific information. Their input was particularly notable in areas of observation and data collection in the fields of biology, environmental science and astronomy. (Dickinson and Bonney, 2012) This form of citizen science relied on public engagement and a reliable submission of data to scientific societies or universities. As Dickinson and Bonney state, ‘By our definition of citizen science as public participation in organized research efforts, hundreds of thousands of individuals around the world are “citizen scientists,” people who have chosen to use their free time to engage in the scientific process.” (Dickinson and Bonney, 2012: 1)

Citizen science has grown by leaps and bounds in recent years, likely attributable to an expanding access to information technologies and the growth of grassroots advocacy, particularly in relation to environmental science. As Alan Irwin observed in the mid-1990s, citizens need to be active participants in science and the impact it has on the every day. (Irwin, 1995) He also argued that ‘science and technology should be seen above all as *human* activities’ (2) and that ‘communities need to get involved’ (105) in their activities. For Irwin, the nature of scientific citizenship was a dynamic one that characterised contemporary society (1995). This trend to advocacy through citizen science continued and expanded as internet technology grew and scientists saw ways to not only educate but also engage large communities in supporting and learning about their research. Dickinson and Bonney see ‘large-scale citizen science as a microcosm of the changes that are occurring in science and society owing to the explosion of the Internet and the social web.’ (2012: 3) For some, the growing participation in citizen science ‘represents a fundamental change in the way that scientific work is distributed within society.’ (Good and Su, 2013: 1931)

In environmental science, a lot of the literature exploring citizen science projects suggests that citizen science functions primarily to empower and encourage the public to increase their understanding of and support of science. (Dickinson and Bonney, 2012) Citizen science, they argue, reaches the public and transforms them. The projects on offer largely support this view, but ask for a limited engagement from the public around areas which pose less risk to the success of the project. The majority of citizen science games appear to avoid tasks seen as too complicated or skilled, such as data analysis or laboratory experimentations. Projects are mostly about data collection on a large scale: the public submitting a count of how many birds they have seen in their back garden (Audobon Bird Count), or through basic data analysis: counting images of penguins in Antarctica (PenguinWatch). Good and Su describe these forms of activity as encompassing ‘an emerging collection of approaches for harnessing such distributed human intelligence’ (2013: 1925). They lament the lack of research and resources around the best ways to use these forms of human-powered engagements across various ‘scientific domains’. (2013: 1925)

For many researchers involved, citizen science is seen as a largely positive experience for the member of the public who is contributing to the scientific project: they are being educated and motivated to contribute to a greater good. (Cockshut, 2014) Many of the projects are highlighted and promoted for their ability to engage in public education or stewardship activities. (BBC, 2013, 2016) By engaging with citizen science, professional scientists can expand the culture of academic science beyond what are viewed as their primary markers of success, namely publications, teaching, and the wider scientific community. (Dickinson and Bonney, 2012) But that doesn't mean it's not viewed by some as a risk to those key values: supporting and developing a cohort of citizen scientists can require resources and take time away from what are seen as core academic pursuits. (Trueille and Das, 2014) What remains less explored, in the predominant literature around citizen science as a whole, is the benefit that these contributions can make for the scientists themselves, particularly beyond those key values that Dickson and Bonney refer to above.

A good example of most current *citizen science* or *crowdsourced research* projects are those housed on Zooniverse, an online portal to (as of mid-2016) over forty different projects that the public can get involved in. (See *Fig. 1* below.) They include projects that go beyond science as well, covering the arts and humanities and the social sciences.[2] Most of the projects involve visual cognition or data processing activities. In some citizen science projects, thousands of participants are credited with contributing to a project. In PenguinWatch 2.0 (where citizen scientists are asked to classify penguins, chicks, and eggs by pointing and clicking on their images), it notes (as of June 2016) that almost 4 million images have been classified by over 36 thousand volunteers. (PenguinWatch)

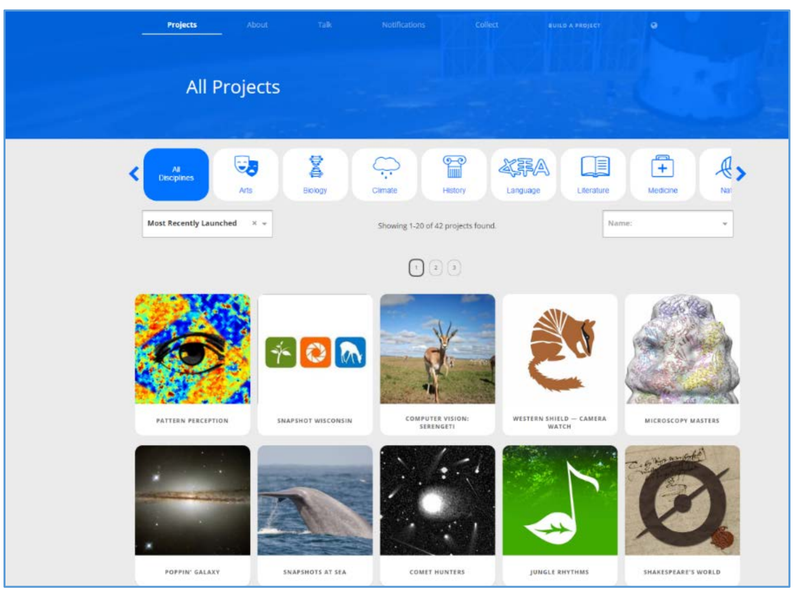

Figure 1. Screen capture of the Zooniverse citizen science portal (www.zooniverse.org), 2016.

As academics are increasingly taking advantage of these new forms of digital and social web-related access through a range of citizen science projects, so have some begun to think of new and alternative ways to tap

[2] It's worth pointing out here that there are an increasing number of crowdsourcing activities that support non-scientific research, such as Shakespeare's World (asking participants to view and identify words on handwritten papers from Shakespeare's contemporaries), https://www.shakespearesworld.org/#/. For the sake of this chapter, however, the focus is exclusively on the crowdsourcing activities that have a specifically scientific orientation, namely *citizen science.*

into this large pool of potential volunteers to support their work and deal with the increasingly massive amounts of data that require processing and handling. In the case of a few of these scientists, some are using a game platform to engage their citizen scientists.

The earliest known example of a game with a purpose was released in 2004 and the first known citizen science game, Foldit, was released in 2008.[3] With data suggesting that for many, video games are their primary leisure activity with many hours spent playing them per year (ESA, 2016), early proponents of using game platforms to facilitate certain largescale research needs, Luis von Ahn and Laura Dabbish, advocated tapping into this excessive time commitment to support research: 'What if this time and energy were also channeled toward solving computational problems and training AI algorithms?' (2008: 59) These games also wanted to tap into something else that citizen science was already doing: gather together a large pool of humans to cope with the massive output of data now overwhelming many scientific fields. (Curtis, 2014) For Trueille and Das (2014), they also argue that using what they term a 'massive open laboratory' through their game EteRNA is an effective way to mitigate the growing problems they see affecting the scientific method in an increasingly big data research environment:

> A growing spate of controversies, retractions, and fraud cases highlight the susceptibility of modern biology to untruths. Despite an elaborate peer review system, issues such as data manipulation, lack of reproducibility, lack of predictive tests, and cherry-picking among numerous unreported data occur frequently and, in some fields, may be pervasive. Some of these issues are further intensified by what is now a hallmark of modern biology, the use of high-throughput experimental techniques. … In our view, however, hypothesis generation and experimental tests by creative scientists are what make science exciting and truthful. Therefore, 3 years ago we began to explore a new idea: rather than allow growing experimental data to overwhelm hypothesis generation, perhaps a larger number of people could be recruited to deeply analyze and design experiments. The result is what we term a massive open laboratory model for science. (507)

In EteRNA's case, this meant creating what may be seen as a fairly rudimentary puzzle game, which taught the basics of RNA sequencing, but which established the gamers (or the citizen scientists) as an integral element of their overall laboratory strategy.

In the case of the game Fraxinus, the goal was a genomic study of the pathogen which is currently decimating ash trees in Europe, and designers utilized not only a puzzle-based casual game but released it on Facebook. The idea was to expedite the release and engagement of players in the problem, due to the time-related pressure the researchers faced. The game, designed by Dan MacLean at Sainsbury Lab in the UK, was released within months of the first case of the disease being discovered in the east of England.

[3] The earliest games with a purpose go back as far as 2004 when researcher Luis von Ahn created a game called ESP, which was an image recognition game. Though it was not specifically a science game, it drew on similar principles of using large human-based computation and visual cognition techniques. This was largely built from success von Ahn and his colleagues had experienced from developing the ubiquitously familiar reCAPTCHA program which found great success verifying the superior ability of humans to recognise lettering as compared to computing. (von Ahn *et al*, 2008)

(Rallipalli *et al*, 2015) This approach drew on social media, game play, and an urgent research need to propel its work forward.

For the creators of Foldit, following its notable early protein folding successes (Khitab *et al*, 2011), it provided compelling early evidence in support of the hypothesis that using a large, crowd of skilled puzzle solving players could produce a result and be an effective tool for researchers. As they write,

> Although much attention has recently been given to the potential of crowdsourcing and game playing, this is the first instance that we are aware of in which online gamers solved a longstanding scientific problem. These results indicate the potential for integrating video games into the real-world scientific process: the ingenuity of game players is a formidable force that, if properly directed, can be used to solve a wide range of scientific problems. (1177)

But perhaps most interesting about this intersection of the gamer with the scientist is the notion of creative problem solving, or the shared making of knowledge, as stated by Trueille and Das (2014) above and by Eiben *et al* (2012) below:

> crowdsourcing complex computational protein-design problems with a community of game-developed experts can be an effective way of creatively sampling the potential sequence space for the design of active-site loops that modulate enzyme activity. (192)

3. Studying When Citizen Science Meets the Game

I recently sat with a group of my first year undergraduate games design students to discuss citizen science games. These were predominantly male, aged 18-27, and self-proclaimed avid gamers used to blockbuster games like *Fallout 4*, *Call of Duty*, or *World of Warcraft*. These students were used to my challenging them to think beyond the typical scope of the commercially viable game and consider alternative games and their impact in other areas. I felt this was an important part of their learning process, particularly as they were fledgling game designers about to embark on a career in a field that has seen radical growth and shifts in its decades of existence and a field that was still under development.

Most had never heard of citizen science games before, however. When I explained that these were games designed to help analyse actual scientific data using game platforms and puzzlers, most were politely curious, yet largely uninterested. How is that even a game, asked one of them. Another noted that they'd heard of games like that, but they'd presumed they were pretty boring to play. A few were intrigued by the idea and discussed them in more detail. Perhaps, one posited, games like these might improve the negative perceptions of games and gamers. Another proposed that introducing more games like this in school could make certain subjects more interesting to learn. This inevitably segued to some students arguing that a lot of so-called 'serious' or educational games were poor quality and that students only played them in school as it was better than working out maths problems on a worksheet. I asked them if they'd feel 'better' about playing a game if they knew it was supporting a greater aim or answering important questions. A number of them agreed, but a few remained ambivalent. Games are meant to be fun, one remarked, doesn't really matter what kind of data they are built on or if playing it helps in some other way—it just has to be fun to play. And if it wasn't fun, I asked, but you still knew it was helping with research? Then, he responded, I probably wouldn't really bother to play it really. At least not for long, he added. To me, this ad hoc conversation with my students raised a few interesting questions around the nature of games and whether or not a citizen science game—a game which may be more about purpose than simply fun—has not only a role for the creative making of knowledge but could also be regarded as part of the canon of videogames.

As discussed earlier in this chapter, there are increasing examples of games being used in non-entertainment contexts, including serious or educational games, gamification in business or health, and now the emerging citizen science game. And while academic research has been interested in studying a range of ways that games and play are impacting modern society, there is less work done around the interactive dynamic between the scientist and gamer in the citizen science game. Based on my own work looking at the experience of play in a massively multiplayer online roleplaying game (MMO) (Cockshut, 2012), I was interested in how these fledgling citizen science games might compare to the genuinely global, massive for-entertainment game, particularly in relation their community relations and approach to game-making. In the summer of 2014, I conducted a limited online ethnographic study of a small selection of citizen science games, primarily interested in the experiences of its players and scientists around their motivations for creating meaning (scientist) and making knowledge (gamer) through such a game and how it might more effectively support research and public engagement going forward. To inform this initial study, I used publicly available online forum discussions, anonymised online communications with participants, and academic journal articles and media reports to draw insight.

Research conducted online is no longer viewed as a new phenomenon; it has become established as a valid (and source) of investigative enquiry (Lee *et al*, 2008). The work of Christine Hine (2000) and Annette Markham (1998; 2009) are considered seminal contributions to thinking through the methodological and ethical problematics of online research. A holistic approach to designing online-based research is particularly in Hine's work on researching the internet in 2000. As Hine writes, 'An ethnography of, in, and through the Internet can be conceived of as an adaptive and wholeheartedly partial approach which draws on connection rather than location in defining its object.' (2000: 10) I have utilized this adaptive and connective approach in my own study of online persistent game environments and their complexities as expressed through the actions of play, community building, and competition. (Cockshut, 2012) This approach has been supported through the work of Fields and Kafai (2010) when they applied this idea of a 'connective ethnography' (drawn from Hine's earlier work, among others) to trace gamer practices across the 'different spaces' of play (2000: 91), an approach that greatly affirms my own. The notion of the effective connective online ethnography requires engaging with varied tools and techniques to pull data together. Taylor describes her research practice as 'bricolage, pulling from a variety of techniques, tools, and methods to understand a mix of practices, representations, structures, rhetorics, and technologies'

(2006: 17). I found echoing a similar approach to Taylor's to be effective in my own ethnographic work in these first generation citizen science games, particularly in relation to adapting and modifying my research collection methodology around the needs and practices of the players themselves.

My preliminary, smallscale study of these games and their creators (scientists) and knowledge makers (players) was interested in the following:

1. Drawing out which values matter to each group and what sustained their contributions to (gamers) or development of (scientists) these types of games
2. Learning what, if any, community had developed around these games and how those relations are being sustained

The aim of this work was to conduct a preliminary, scoping study to inform potential social science-related research in and around player experiences in citizen science games. While the data generated from this study represents a small sample and should not be viewed as conclusive, they do provide some interesting areas which warrant further study.

About the Citizen Science Game

For the purposes of this preliminary work, three citizen science games were studied: EteRNA, Foldit, and Fraxinus. Each of them have built a game platform around a specific set of data that can be analysed and handled better using human-based computational skills. As one scientist described it, their game was designed to take advantage of 'using the crowd as a human super computer'[4]. All of the games are designed to be accessible, free to play, and understandable to a non-scientist. While Fraxinus is accessible as a Facebook-hosted game (Rallapalli *et al*, 2015), the other two have dedicated Web sites, with forums and information housed on them as well.

Of those players interviewed for this preliminary study, I observed that while the majority had little previous engagement with mainstream, commercial videogames, some had had experience playing casual or puzzle based games. I also noted that some had a computing or science-related background, though most did not. And among the two Web-based games studied, I found that there were active, engaged communities of players who had formed subgroups and other forms of communication and interaction to support their activities. This had also expanded to creative forms of engagement and knowledge making between scientist and player through the game.

In the following two sections, all of the comments and communication with scientists and players have been anonymised, unless previously published elsewhere (via the media, the game sites or academic

[4] Scientist 1

journals or publications). I spoke with players in two different citizen science games and with scientists associated with three different games.

The scientist as creator

In this section, I highlight certain core values that emerged from conversations with and comments by scientists involved in designing and managing citizen science games.

Value 1: Has a computing-based problem which needs human input

Perhaps the most telling motivation for a scientist to adopt a new approach like crowdsourcing research is when a limitation is reached in their own research approach. When David Baker and his colleagues ran into such difficulties, they innovated a method which eventually expanded into a citizen science project, Rosetta@home, in 2005. And from this project eventually emerged the Foldit game.

> To enable the more comprehensive searching necessary to find the low-energy native energy minimum, we decided to enlist the help of the general public. We created a distributed computing project called Rosetta@home … in which volunteers donate spare cycles on their computers to carry out folding trajectories. (Baker, 2014: 225)

For some, the human ability to spot patterns and make intuitive leaps are key to the citizen science game. In the case of EteRNA, Rhiju Das acknowledges that while computing programs try to decipher and build new strands of RNA, none could match the human ability to pick up on subtle, emerging patterns (Gross, 2012) to effectively predict new ones. ‘We're relying on humans to do something computers can't do, which is create hypotheses,’ Das said. ‘There's no computer who can do that. They don't have imaginations.’ (Das in Gross, 2012) And for Das, the decision to make his citizen science project into a game was due to, he says, certain qualities that make online gaming fun.

> The most addictive online experiences, they have certain qualities that are game-like. … They're social. You have a chat. You feel like you're in there with some other people and it also has to give you a huge amount of positive feedback. (Das in Gross, 2012)

Value 2: Has a lot of data and needs a lot of resource

In discussions with one scientist, he explained part of the driving force behind creating a citizen science game was having ‘a lot of data to churn through’[5] that needed processing and for another, the approach was deemed necessary in order to speed up the design and to ‘create a pool of volunteers who could scale human-generated experimental design and analysis along with biochemistry's rapidly expanding experimental throughput.’[6]

Value 3: Isn’t afraid to be imaginative and take risks

[5] Scientist 1

[6] Scientist 2

A number of researchers have pointed to how their disciplinary background pushes them to try new things; and considering that the majority interviewed were from a bioinformatician background (a relatively new interdisciplinary scientific field of research that brings together computing, mathematics, statistics, and engineering to study biological sciences). We '[bioinformaticians] like to try new approaches and aren't intimidated by the mechanics of processing and taking in data this way,'[7] one explained to me.

For some, the potential output is worth the risk of use a game to support research even when segments of the scientific community may not yet fully embrace the idea: 'At the beginning, we weren't sure this approach would work, which is why we set the game up to be continually changing and improving. I think initially there was some 'naysaying', but hopefully through some of [its] successes of [the game], as well as other games that involve the public in scientific research, that has changed.'[8]

Value 4: Appreciates the value of skilled players

At least two of the researchers behind one of these games had a direct experience with gaming, which likely contributed to their openness to using game platforms to support areas of research. (Das and Trueille, 2012; 2014) For other researchers, the unique contribution that players make to the process has been invaluable:

> The 'skills of top players far outweighs anything I could have imagined' (Adrien Trueille, in Gross, 2012)
>
> '*FoldIt* players in the last 2 years have made a number of quite important contributions: they solved the structure of a retroviral protease, developed new algorithms for finding low energy protein conformations and improved a *de novo* designed enzyme by rather large-scale redesign of the active site. (Baker, 2012)

For the scientist as creator, the values of innovation, risk-taking, and resource-reliance are relevant and their needs for support enable them to work with and valued a skilled non-scientist community.

The player as knowledge maker

Without the player, the citizen science game cannot achieve its potential: making the knowledge that supports or innovates the wider research aims of the project. In this section, I highlight what players value whilst playing and making knowledge in citizen science games.

Value 1: Mutual respect and scientist engagement

For the players, a tone of a shared responsibility and ownership is expressed and enacted through the goals of the game. As one player said, 'Our game, our scientists and we are their players. This is a joint adventure.' (1)

Value 2: Emotional investment and community involvement

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[7] Scientist 1

[8] Scientist 3

For many of those interviewed, an emotional investment and attachment to the game was expressed: 'I really love the idea with citizen science. I feel the term describes well what I am. I'm a citizen doing science… my feeling … is empowerment. We play, fail and succeed.' (2)

Another player discussed the impact that the community has had on their emotional investment and commitment to the game:

> I think the reason that I'm so emotionally invested … is because of how much I have gotten out of it. I've made friends and I've gotten the chance to be part of something that not everyone can be a part of. I also found a lab to work at due to my involvement in [the game]. [It] has helped to shape my life in a multitude of ways, and I guess that's why it means so much to me. (3)

The shared sense of involvement is expressed by this player, particularly by referencing their own work using the plural pronoun: 'We all help and contribute. But we do so differently. We try make up for the weaknesses and for what is lacking.' (4)

Value 3: Contributions and work

Work and contributions were important to many of the players I chatted with. Terms like problem solving, 'work', and 'help' suggest an active, productive engagement with the 'The way I see it, the faster we get the new players level up, the more we can all contribute to science. We have problems to solve.' (5) For another player, the association with a greater aim through playing a citizen science game appears unmistakable: 'I work for something.' (6)

And for this player, there is the idea of not only actively supporting the project ('help the protein') but also the notion that they can develop and hone new skills and abilities through playing the game: 'I want to help the protein be what it should be'... 'I like to measure myself against something…' 'I get to use abilities that I didn't know I had' (7)

Markers of contribution can be self-determined or encouraged through the game itself. In fact, for my own participation in EteRNA, I was given a certificate marking my own contribution (see *Fig. 2*).

> LadanC has significantly contributed to Eterna(http://eternagame.org), the internet-scale molecular design project, in the following ways:
>
> - Overall percentile of 88%, rank of 27374 out of 233329 registered participants from January 2011 to June 2016.
> - Contributed to peer-reviewed papers:
>   RNA Design Rules from a Massive Open Laboratory. Lee J., Kladwang W., Lee M., Cantu D., Azizyan M., Kim H., Alex L., Yoon S., Treuille A., Das R., and Eterna participants (2013). In revision at *Proc Natl Acad Sci USA*
> - For more information, you can view this player's profile
>
> This work is certified by principal investigators Profs. Adrien Treuille (Computer Science, Carnegie Mellon University) and Rhiju Das (Biochemistry Department, Stanford University School of Medicine) at the link http://eternagame.org/certificate/171728.

Fig 2. The author's 'certificate' of participation in EteRNA (2016) and markers of recognition for that work.

For the player of the citizen science game, the result of this sample set of interviews suggests that they value not only a sense of mutual engagement and respect, but also favour the opportunity to contribute meaningfully to both the activity and community of their respective games. The process of gameplay is not merely about the outcomes of the game, it appears, but also about the contributions and emotional investment that they make.

4. Reflecting on citizen science games: challenges and possibilities

It seems clear that citizen science games signal an interesting opportunity for both the scientist and game player to collaborate and make new areas of knowledge together. It appears to not only enable the non-scientist to contribute meaningfully to timely research, but to do so in a way that could generate more concerted and regular interactions between these two seemingly disparate groups of people. There appear great potentialities for community building, empowerment, and outcomes-based commitments to surround these efforts and to sustain long term engagement. It is not without its critics and degrees of cynicism, however. Recollecting my own informal discussion with some of my games design students, it may remain a challenge to draw enough mainstream players to what may be misconceived as a boring or 'serious' game, and having a significantly large group of skilled gamers are critical to make a suitable dent in the huge amount of data that requires analysis. (Gross, 2012)

Coupled with this is the academic cynicism that may greet projects of this type. For one of the scientists involved, the cynicism may relate to different backgrounds and training: 'A lot of bench based scientists don't make the mental leaps about how distribution of a problem and highly parallel consideration can help, it isn't in their training to go from a reductionist philosophy to seeing how large scale involvement could work.'

For some, the problems of perception within the academic community pose a genuine risk to the scientists who engage in these types of projects: 'The major current barrier may … be the career risks that these projects pose for their creators. In particular, videogames, which appear critical for recruiting scientifically engaged citizens, are generally viewed as incompatible with 'serious' or rigorous research.' (Trueille and Das, 2014: 508) This suggests that producing or supporting citizen science games as a legitimate research platform could be punitively reacted to in some quarters, which could hinder the willingness of some to innovate in these areas.

For another academic, he views the cynicism as fading as and when these games successfully make research discoveries: 'I think initially there was some 'naysaying', but hopefully through some of the successes of [our game], as well as other games that involve the public in scientific research, that has changed.… Hopefully we are contributing to the view that gaming isn't wasteful and can be a legitimate way to do science.'

Another area of concern, which a few players interviewed raised, relates to ethical issues surrounding games of this sort. One concern related to players being encouraged to volunteer excessive hours in support of the project: ''I recalling *(sp)* watching a … video with one of the researchers speaking, a while back. He was boasting about getting players to play for 24 hours in a row. And I thought to myself, this is irresponsible.' (Player) And another added this thought: 'Scientists are sometimes blind to the side effects [of excessive playing] as they often don't play the game or follow chat.' Being mindful to the ethics and dynamics of work in this type of maker dynamic may require further consideration or study into the expectations placed on players, even if unconscious.

As with any new endeavour, particularly one that puts together scientists who may not ordinarily work with or manage large communities of volunteers with players who are clearly passionate about supporting their games, a great deal can be learned about what does and does not work. A good indication of this has been how these games continue to expand and grow, such as Foldit now developing Nanocraft and more recently EteRNA's expansion into research involving tuberculosis. Not all games remain active, however, such as in the case of Fraxinus, which stopped collecting data in 2015. (Rallapalli *et al*, 2015)

Probably one of the more exciting possibilities relate to where citizen science games could go and their potentially transformative impact on research and community building is in the recent adaptions and modifications made at the EteRNA game site. EteRNA's origins as an RNA building game is seeing cross-disciplinary applications beyond RNA alone. In 2016 it is launching an endeavour to support developing diagnostic kits for tuberculosis that can be used at home and in developing nations where access to conventional diagnostic approaches are typically far more limited. (EteRNA, 2016) Scientists appear to not only have made improvements and are branching into a new area of research—that of optimising the EteRNA community to branch into an area where their puzzle solving potentialities are particularly useful by identifying RNA combinations that could help build a basic, home-use tuberculosis diagnostic kit aimed at the developing world—and aiming to build on not only what is well established by engaging with their most loyal and supportive gamers, but also by providing a key goal (or quest, if one wishes to use a game design-related term).

Directly addressing the EteRNA players and prospective player in a promotional video uploaded on the game's site, Rhiju Das, the project's principal investigator, outlined the game's new direction for players:

> To help us get ready to target tuberculosis we have made two major updates to the EteRNA project: first, veteran players and developers have created a new, beautiful set of puzzles so within a couple days of play you will not only understand the basics of RNA design, but the tools and feedback you'll get; second, we've completely expanded the experimental throughput of EteRNA. Now, every month, if you can get us one million molecules, we can synthesize all of them and process them through the supercomputer and get them back to you. We hope that you'll join us and if we succeed, your designs and your puzzle solving strategies will have an actual impact on the future of medicine.

5. Conclusion

This exploration of the citizen science game—which brings together two very different groups to collaborate—highlights an innovative example of what *making knowledge* can look like in novel applications. It is already showing promising signs of being an effective tool. (Khitab *et al*, 2011) As with other areas impacted by videogames, crowdsourcing, and gamification, it appears that citizen science games demonstrate an emerging field which could have a potentially significant impact on other areas of academic research. While the player is critical to the success of a game of this nature, the engagement of the scientific team behind it is just as important.

As Star and Griesemer noted in their work looking at early 20th century examples of citizen scientists and professional scientists collaborating emphasized, 'Scientific work is heterogeneous, requiring many different actors and viewpoints. It also requires cooperation.' (1989: 387) And it would seem that this cooperative element is what is critical to the success of these citizen science games. Sustained, regular contact between scientist and player; meaningful ways to make and develop contributions (as well enunciated through EteRNA's commitment to not only update its game but engage closely with committed players); and even employing participatory methods going forward when designing a new game. All of these require consideration when developing games of this nature, particularly when so much is at stake for the scientists involved.

Another consideration worthy of further research is the fact that these games could represent a new type of research methodology, one which could be considered not only in relation to games for the physical sciences, but also in the social sciences or the humanities. Whilst this preliminary study suggests that communities can and do build around citizen science games in much the same way as commercial games, it is also clear that how these communities form are unique to the 'citizen science' aspect of the process and that this requires further study and consideration going forward. If, as Trueille and Das (2014: 507) note, 'creative scientists are what make science exciting and truthful', then surely working closely with the intuitive, imaginative gamer can only support and promote these important areas of work going forward.

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