akademisk kvarter
academic quarter
Volume 11 • 2015

When does leisure become work?

An exploration of *Foldit*

Ricardo Vidal Torres *is a doctoral student at the Département de communication, Université de Montréal. He is interested in collaboration, and the relationship between science, technology and society, particularly how technologies are reinterpreted, redesigned and reformulated in different contexts.*

Lorna Heaton *is Professor at the Département de communication, Université de Montréal. Her research interests are collaboration with and around information technologies. Specifically, she is exploring how the division of labor in science is changing with increasing computerization and the involvement of new actors.*

Abstract

This article explores the tensions between game play and contributing to science within *Foldit* (http://fold.it/portal/), an online puzzle game and participatory science project in which participants fold proteins in novel ways. No prior scientific knowledge is required in order to play, but solutions developed by players have led to important scientific discoveries. Based on analysis of online exchanges and interviews with a number of players, we examine the tensions between the experience and pleasure of playing a game and the desire to work and contribute to scientific activity. We examine our players' experiences in terms of Stebbins' (1982, 2007) notion of *serious leisure*.

Keywords science, Internet, gamification, participation, crowdsourcing

Introduction

It has become clear in the 21st century that leisure is a integral part of how we express ourselves and compose our identities. It is also, from a performative perspective, an activity that we spend time

on and derive pleasure from. The Web has given rise to many new forms of leisure activity, from watching television or video clips, to creating and posting content, to participating in discussions, to playing games online. This article examines one example of a Web-based activity that integrates both leisure and productive elements. *Foldit* is an online 3D puzzle game in which players fold proteins and identify optimal protein structures. Developed by a team of scientists and computer programmers, *Foldit* is thus a participatory science project that invites the contribution of non-scientists. It employs elements of gamification to motivate players to participate and encourage engagement.

We start with the premise that, for many players, *Foldit* is a serious leisure activity. Stebbins (1992, p. 3) defines serious leisure as "the systematic pursuit of an amateur, hobbyist, or volunteer activity that is sufficiently substantial and interesting for the participant to find a career there in the acquisition and expression of its special skills and knowledge." He identifies such activities as unpaid but recurrent and regular. What is more, they require perseverance, and result in experiences, abilities and ultimately self-fulfillment that are significant for participants (Stebbins, 1982, 2007) The word "serious" stems from the descriptions made by amateurs, hobbyists and volunteers themselves, highlighting the importance of these activities in their lives.

We will illustrate how Foldit's success as a scientific project hinges on players' commitment and serious participation. The players themselves find fulfillment in both the experience and pleasure of playing a game and in working and contributing to scientific activity. We analyze a situation in which the balance between the two is upset and tensions arise, leading some players to reposition themselves with relation to the game, their experience of it and their role as workers of science.

Participatory science on the Internet

Although the participation of non-scientists in producing scientific knowledge is not a new phenomenon (Charvolin et al. 2007; Miller-Rushing, Primack and Bonney 2012), the development of information technologies and the ubiquity of digital tools and media make the involvement of amateurs and the general public in scientific research a viable research strategy for some problems. Digital

technologies are playing a pivotal role in the emergence of a structured amateur practice by providing opportunities and spaces for large-scale participation (Lievrouw 2010). This multiplication of arenas for knowledge sharing and aggregation can transform amateurs and the general public into the "invisible workers" of science (Barley and Bechky 1994).

The last decade has seen an explosion of online participatory science projects, as teams of scientists explore the advantages (in terms of reduced time and cost) of large scale and free contributions of participants from across the globe to their research (Nielsen, 2012), and enthusiastic volunteers can engage more easily in projects that match their interests. The vast majority of projects that invite participation rely on large numbers of contributors to provide small contributions that are more or less independent, allowing them to be treated separately and then integrated into a coherent whole, with a variety of mechanisms to ensure the quality of results (Kelling et al 2011; Wiggins et al 2011). In this scientific equivalent of crowdsourcing, amateurs work actively to gather and contribute data (usually observations) or to code or classify existing data (often specimens), across a variety of disciplines from astronomy (Cho and Clery 2009; Nov, Arazy and Anderson 2011), to botany (Heaton et al. 2011), ornithology (Charvolin 2004; Wiggins et al 2011), or biomedical science (Kelty and Panofsky 2014). In some fields, data processing projects leverage basic human perceptual capacities and problem-solving skills. For example, *Galaxy Zoo* asks participants to reduce data by looking at images of galaxies (Cho and Clery 2009), *Click to cure* invites participants to identify forms and colors and to calculate proportions within the images of tumours posted on its Website, while *Eyewire* and *Foldit* ask players to solve 3D puzzles (Cooper 2011; Kawrykow et al. 2012).

Non-scientists are seldom involved in the definition of research questions or the interpretation of results (Lievrouw 2010; Nielsen 2012). Although their contributions are generally restricted and channelled by projects defined and managed by researchers, their work may lead to the actual production of scientific knowledge in the form of *discoveries* (ex. new galaxies), *techniques,* (ex. algorithms for protein folding), or *research directions* (ex. new questions about the impact of climate change on species distribution).

Bos and his colleagues (2007) contend that a major issue for online collaboration between distributed scientists and volunteers is the need to motivate contributors while ensuring the credibility and scientific validity of the data. Previous studies of participants in online science projects suggest primarily relational motivations: a desire to work cooperatively, to share skills and knowledge, as well as to belong to a community (Raddick et al, 2010). Enjoyment and identification with the project goals are also prime motivations (Nov, Arazy and Anderson, 2011; Raddick et al, 2010). Many participatory science projects also incorporate mechanisms for recognizing their most active or productive participants, and often provide lists of publications produced by the project, some of which include unpaid contributors as co-authors (Lievrouw, 2010). In this context, Nov, Arazy and Anderson (2014) stress the importance of the time and skill invested by participants for the project's longevity, as well as the volume and value of their contributions. The increasing use of elements of gamification is an indication of project designers' interest in establishing pleasant environments that will encourage the massive, long-lasting contribution of non-professionals (Kawrykow et al. 2012; Wiggins and Crowston 2015). What is more, game-like environments for participatory science projects are fast becoming an object of research (Good and Su 2011; Schrope 2013; Bohannon 2014).

Gamification is the term used to refer to the use of elements of game design in non-game contexts, such as in educational software, military simulations, and so on (Deterding et al. 2011; Groh 2012). The principal indicators of gamification are clearly identified goals, recognition of achievement using badges, elements of competition, team collaboration, progression through different levels, and the possibility of earning and accumulating points (Zichermann and Linder 2013; Paharia 2013). In an entrepreneurial context, Parharia (2013) stresses that gamification is not game creation, but the use of elements of game context as a motivational strategy. The instrumentalization of elements associated with play activity is also present in participatory science. In fact, in addition to interest for the scientific domain, the presence of gamification elements appears to be an important component of participants' motivation and involvement in participatory science (Prestopnik and Crowston 2011). Nicholson

(2012) warns of the dangers associated with replacing intrinsic motivations with extrinsic (game-related) ones.

Foldit and the New Chapter

Developed in 2008 at the University of Washington (Seattle, USA), *Foldit* invites non-scientists to participate in identifying protein structures using an online game composed of three-dimensional puzzles (Cooper, Khatib et al. 2010; Khatib, Cooper et al. 2011). Proteins are key components of all biological activity, and the function of a protein is strongly related to the way it is folded and its structure. Consequently, a better understanding of protein structure is an urgent scientific task that opens the way to designing proteins that could be mobilized in the fight against disease, such as Ebola (Puzzle 1000). However, this task is a complex one, given the multiple ways in which proteins fold. Bioinformatics scientists have been using computer modeling to try to predict protein shapes, based on the idea that a protein will eventually fold into its lowest energy shape and stabilize. Enormous effort has been invested in developing algorithms to restrict the number of configurations that must be examined, but computers are still unable to reliably predict protein shapes.

Foldit was developed as a way to harness humans' innate perceptual abilities and the innate workforce of a mass of persistent gamers. In fact, human beings are often better than computers at pattern matching and 3D problem solving. The underlying idea is to analyse players' solutions and use this information to inform algorithm design that will eventually automate the process.

In order to play, participants must install a client (software) on their computers that will enable communication with a central server as well as with other players. Different puzzles are posted, usually for a week at a time. Each puzzle is a three dimensional protein that players will try to stabilize using tools provided by the platform to move, rotate, bend and shake the images of the protein. As with many online games, *Foldit* has puzzles of different difficulty levels, and other elements of gamification, such as lists of top scoring players, overall and per puzzle, and a congratulations notice when a puzzle is successfully solved. Players can stop playing, save their progress and later return to the same puzzle. They may play the game individually, or in teams.

The *Foldit* website also includes spaces for exchange and discussion between the scientific team and players. The home page and the *Blog* present posts by the *Foldit* team, with possibilities for comments, while players can initiate discussions in the *Feedback* and *Forum* sections respectively. There is also a *Wiki* containing information on proteins and the science behind *Foldit*, game tutorials and recipes advice (scripts and scripting tutorials on how to automate some parts of solutions).

Once a puzzle is closed, solutions, and the strategies of players to derive them, are analysed using the Rosetta molecular modeling suite. The lower the energy of the shape, the higher the number of points, so that high scoring solutions are potentially the real shape of the protein. Probable solutions are further tested using X-ray diffraction, or sent to *Critical Assessment of Techniques for Protein Structure Prediction* (*CASP*), an international bioinformatics competition that has been held every two years since 1994. Although they may not have biochemical training, *Foldit* players perform very well at CASP challenges, finishing at or near the top in every competition, since much knowledge is encapsulated in the game's algorithms. Nielsen (2012, 148) suggests that remaining disparities in expertise are counterbalanced by Foldit players' greater time commitment.

Foldit is thus both a competitive game and a computer science experiment, a hybrid object. The team continually strives to improve *Rosetta* by recording and analysing players' puzzle-solving activity (Cooper 2011). While *Foldit* has proven an effective research method (Marshall 2012; Armstrong Moore 2011), it is constantly evolving. In this context, in January 2014 the *Foldit* team released an update that the called the New Chapter. The implementation of the New Chapter was accompanied by a flurry of exchanges between players and with the development team. This update produced important changes in the way points were calculated, and in the internal calculations of certain tools, which affected primarily the recipes scripted by players. What is more, solving puzzles now required much more computing power, which slowed gameplay and reduced pleasure for some players. In short, the implementation of the New Chapter prompted a situation in which the balance between the scientific goals and the ludic aspect of *Foldit* was, at least temporarily, destabilized. It thus provides an excellent case from which to explore the tension between leisure and work in the context of citizen science.

Methodology

This research takes a qualitative approach inspired by the principles of grounded theory (Glaser and Strauss 1967; Paillé 1994), and is based on observation, interviews and analysis of exchanges on the *Foldit* platform. Specifically, directed observation was conducted from January to March 2014. We also conducted eight semi-directive interviews by *Skype* (n=4), email (n=2) and face to face (n=2). Since the general goal of the research was to analyse relationships between players and the scientific team of *Foldit*, we first prepared a list of players the most active in online discussions. Potential participants were contacted individually through the site using its internal messaging system. The interviews covered participants' interest for *Foldit*, their motivations, ways of participating, relationships with *Foldit* staff, and their reactions to the New Chapter. Given the small number of interviews[1] and the exploratory nature of the research, we have no pretentions of representativity. What is more, our selection criteria – active participation – certainly goes some way to explains the extent of participants' engagement with *Foldit*. Our participants were not occasional players. Their cultural background, professional experience, age, education, and so on, were however, extremely varied.

We also analysed exchanges in several spaces on the *Foldit* platform: *Portal*, *Blog*, *Feedback*, *Forum* and *Chat* sections. In order to provide focus, we limited our analysis to posts concerning the New Chapter in a three-month period from January to March 2014. In total, we analysed 234 comments/items. Unlike the interviews, these exchanges focused on the New Chapter and reflect concerns on the part of both players and the project team for the balance between play and scientific aspects of Foldit, as we will discuss in the analysis.

Our analytic method consisted of identifying themes that emerged from the data, continually going back and forth between our research question and our corpus. Morse (1994) describes this oscillation between the conceptual and the concrete in terms of four decisive cognitive moments: understanding, reducing, abstracting and recontextualizing. In our analysis here, we limit our discussion to tensions that emerged from the coupling of play/science.

Analysis

In this analysis, we first discuss *Foldit* players' sense of identity and their motivations in relation to *Foldit*. We then discuss tensions between contributing to science and the experience of playing a game, as highlighted by the New Chapter. These tensions show up in terms of time invested, and competencies developed and used during play. We draw on Stebbins (1982, 2007) notion of serious leisure to explain *Foldit* players' reactions to the New Chapter. We conclude our analysis by discussing the emergence of a new tension, between work and leisure.

Player and contributor: a dual identity

As noted above, the players we interviewed are strongly engaged in and committed to *Foldit*. For them, *Foldit* is clearly a serious enterprise (Stebbins 2007, 2012). Their unpaid, regular participation requires perseverance and is associated with "personal commitment to practice and learning, openness to possibilities and freedom from personal financial interest" (Edwards 2014, p. 387), experience and abilities and which is significant in terms of personal growth and experience (Stebbins 1982, 2007).

Players recognize *Foldit* as a hybrid object – part game, part scientific project. In particular contributing to science is an important motivation, Michelle[2] explains: " we might really discover something. It can help advance science, it could prevent people dying … so it's important" (Michelle, lines 302-307). Furthermore, *Foldit* allows them to contribute without having a scientific background, as Yves notes: "I'm glad to know that we can contribute to science [...] without being a scientist, I can become involved in research" (lines 391-394). Firas Khatib, a member of the *Foldit* team confirms that "most of our best players don't have a scientific background. We ask them 'how much chemistry experience do you have?' and they answer 'I haven't studied chemistry since high school' … Not just a few, but three quarters of our best players have told us that" (lines 143-146). Both altruism, and self-benefit, two motivations identified as significant by Stebbins (2001), are thus present among most, if not all of our participants.

Committed players voluntarily invest considerable time and resources. Some run Foldit puzzles 24 hours a day on their computers. For example, Yves uses two computers that have run continuously

for the past two years. In addition, "evenings, I work by hand [that is without recipes] and I prepare my protein and then I mix the recipes" (Yves, lines 327-330). They often refer to their activity as work. The sense of work in these references is of productive activity, undertaken systematically and regularly. Michelle used to play one puzzle at a time using one recipe "not like in a factory", but as she gained experience, she found this artisanal method unsatisfactory. Now she launches a combination of recipes, goes to her paid job and checks the progress and tweaks her commands when she comes home. She thinks that, like her, most players "play every day, several hours a day" (Michelle, lines 251-268). This is in line with Stebbins' observation that preprofessional amateurs follow a path paved with "necessity, seriousness, commitment, and agreeable obligation, as expressed by regimentation (e.g., rehearsals and practice) and systematization (e.g., schedules and organization)" (2012, p. 35) that distinguishes it from playful activity.

Michelle's comment also points to the development of a sense of competence and skill in executing the activity. In fact, players often develop, and subsequently use, considerable understanding and skills in both computer programming and in biochemistry. For some, this sense of accomplishment or of learning something new is a source of motivation. "It's an intellectual challenge […] the pleasure that you feel when you arrive at a good solution after having devoted 50 hours to a puzzle is proportionate to the effort invested" (Bob, lines 104-118). Many veterans and skilled players have learned to program in order to write recipes that advance game play. Exchanges around biochemistry tend to be of a didactic type, with staff coaching or instructing players.

> They're a bit like our teachers – it's not horizontal – we're not on an equal footing, they are our guides and they give us directions [...] they explain to us from time to time the usefulness of something, but without going into much detail... and we have a relatively simple activity to do, so that's the fun part... eh... so it's a bit like... they are our generals. (Brian, lines 602-610).

But *Foldit* is also a game, and the pleasure of playing is also an important driver. As the gamification literature suggests, players en-

joy the challenge, earning points and solving puzzles. Many also appreciate the competitive aspect of the game, either individually or when they play in teams. "The competitive feeling is a great part of folding; groups and players always trying to 'one-up' one another, even within the same team." (Paul, lines 285-287).

Most players identify as both *Foldit* game players, and as contributors to science[3]. The precise balance between ludic and scientific motivations varies among players, and this balance may evolve over time, as the experience of the New Chapter illustrates.

> auntdeen: We all want the game to be as productive as possible - we all have as motivation the desire to contribute to science - but in the end, if we can't derive some pleasure from it, if it isn't a game with enjoyable elements, then we cease to be "players" in one respect or the other.
>
> Mike Cassidy: Sorry, I play Foldit for the science, the science is not something on the side. The only reason I joined years ago was to help do science.
> (One's player's perspective, Feedback, February 11, 2014).

The Experience of *Foldit*

The New Chapter update changed rhythm of game play – it slowed it down and made it harder to run multiple puzzles (clients). Spmm states the problem:

> Several people in veteran chat have just been kind enough to specify the number of clients they used to be able to run and the change they have experienced with NC. [...]In most cases the change is a big reduction, from 7 to 3, 4 to 1 and so on. This makes it very difficult for players on lower spec machines to experiment and play. Even folders on better spec devices have experienced overheating and higher resource consumption so are reducing the number of clients they can run. (Number of clients able to be run on NC, Feedback, March 10, 2014).

These changes generated numerous complaints and even threats to quit the game. Many players took it upon themselves to identify the

problems with precision and help fix them by testing or debugging. Players' well-developed programming skills enabled highly structured exchanges during the New Chapter update. Furthermore, the players showed that they were able to carry out systematic tests, to interpret results and to propose solutions. Exchanges around technical issues, such as changes to the « wiggle » tool that helps refine the protein's structure, were characterized by cooperation in problem solving, as the following exchange illustrates:

> [6:16pm] TimovdL: And the new wiggle is too slow to do a good repair job in a decent amount of time.
> [...]
> [6:18pm] BletchleyParkirc: Sounds like the solution would be to speed up wiggle? and possibly the new scoring function's speed
> [6:18pm] TimovdL: Or get a very rude faster version of wiggle, like it was about 6 months ago
> [...]
> [6:19pm] SethCooperIRC: Do you mean it takes too long to stop running, or takes too long to get to a decent score? By stop running, I mean stop getting points
> [6:20pm] BletchleyParkirc: Apparently both.
> [6:20pm] TimovdL: It takes too long both ways, even the new version takes about half an hour to do one minicycle of my DRW on ED on a decent computer
> (NewChapter - Seth's chat in vet room (second chat), Forum, January 16, 2014)

In another example, one player posted a page of detailed performance measurement results, describing his method and parameters used, followed by his conclusions: "a major change in wiggle behaviour, it is now time sliced, not depending on when the algorithm says it is enough. This is a major game change" and a proposal to replicate the experiment on a faster computer and with other types of puzzles. ([New Chapter] performance (speed) issues, Feedback January 12, 2014).

When the problems continued, the veterans asked for the New Chapter to be withdrawn, at least temporarily:

> auntdeen : We all understand how important accuracy is in our game client, and applaud dev efforts to bring us a better client. Right now, though, NC is simply not ready for prime time. [...] wisky : I am third'ing this motion. Too many bugs in current NC client. It needs more work. [...] gitwut : Even if everything else worked perfectly, I would still be unhappy with NC due to the constant client deaths. Whether it be death by wiggle power (particularly high) or death during scripts, there are far, far too many of them. [...]
> Susume : I agree that there was not enough time to test newchapter, and for fixes to be put in and tested in turn. When fixing a tool causes it to malfunction even worse, that suggests that the new client is really not ready for production. [...]
> (A Request to Roll Back the NC Client, Feedback, February 4, 2014)

In response, the *Foldit* team insisted on the accuracy of the new scoring function and its incidence for science. "Turns out these changes are so critical that asking you to work on our upcoming set of shiny new science puzzles without newchapter would yield scientifically inferior results and be a gross mishandling of your valuable time and effort" (bkoep, quoted in Katfish talks newchapter ! Portal, January 16, 2014).

For numerous players, however, accuracy was seen is opposition to playability. Although the New Chapter changed the usefulness of their recipes, players did not complain much of the waste of time and work they had invested, or that they would need to invest to rework their recipes. In fact, they invested massive amounts of effort in an attempt to describe and fix the problems with New Chapter, and were prepared to write new recipes that would function in the new context. This suggests that it was the subjective experience of game play that was affected. Stebbins (2007) suggests that flow can be a key motivational factor in serious leisure activities. Flow is a sensation of optimal experience that may arise when a rewarding activity (work or leisure) is enacted or performed. According to Csikszentmihalyi 1990, 3-5), the flow experience has eight components: a sense of competence in executing the activity, a sense of

control in completing the activity (in the face of uncontrollable external forces), requirement of concentration, clarity of goals, immediate feedback, sense of deep focus, loss of self-consciousness and truncated sense of time during the activity. Players we interviewed talked about most, if not all, of these components. For example, Bob refers to how he feels in "in synch" with the protein: "Sometimes you arrive at a design that may be asymmetric or bizarre, but you see at once that there's something that attracts you and you know that it works. It's like you recognize its beauty without really knowing how" (lines 120-126). The New Chapter did not affect the game's goals or feedback, but it was a major disruption to players' sense of competence, and especially to their sense of mastery in manoeuvring proteins.

In this context of diminished playability, a number of players began to reflect on their experience in terms of another tension, between play and work. Auntdeen, who wrote that "We play the game to contribute to science - and the community - and for fun" (NewChapter - Seth's chat in vet room, Forum January 14, 2014), complained that the new chapter is "very tedious and boring, making the experience feel more like work than play" (Feedback, February 11, 2014), while Murlow quipped: "All work and no play makes MurloW care less about sciencey goals every day" (Feedback, February 22, 2014).

> Bruno: I must admit that the distance between work (science) and game is sometimes small. In business (and science), we have competition, rewards of the employees (or the researchers), medals etc. Games are said to be useful for children, animals and even adults (it develops or maintain brain etc.). Like dreams. Games are good to develop or maintain creativity, a useful ingredient for work (and research of course). [...] Foldit does the same on a more sophisticated way. Is this a work? Is this a game? Is my work a game or a work? Do I loose [sic] my time on work or on game? Who knows? But both are pleasant times (One player's perspective, Feedback, February 11, 2014).

Players had long been aware of their role in producing scientific knowledge, not only through their solutions, but also through the

translation of their manipulations and strategies into algorithms. The New Chapter's increased precision and the constraints that this imposed on their "fun," caused them to experience the game in productive terms. They started to see themselves as producers of data, and *Foldit* as an obligation rather than as a leisure activity. Many began to question their commitment. The passion that made players such as Yves willingly forego vacation time for two years so as not to miss playing *Foldit* was replaced for many by a sensation of being an "invisible worker" of science (Barley and Bechky 1994). Whereas Barley and Bechky used this expression to refer to laboratory technicians, it seems to us that it applies equally well to *Foldit* players where the site is the lab and the puzzles the equipment through which scientific results are produced.

Godbout (1986) has observed that, as leisure becomes more professionalized and oriented towards performance, it also becomes more like work. Our participants started to feel pressure to deliver results as they had in the past. *Foldit* players employed a variety of behavioural and cognitive strategies primarily aimed at adapting to, rather than removing, these new constraints. Most accepted an ongoing need to negotiate constraints as an unavoidable consequence of their continued participation. This is in line with the findings of Kennelly, Moyle and Lamont (2013), and supports Stebbins' (1992) profit hypothesis for ongoing participation. A few left the game, at least temporarily.

Conclusion

In this article, we have approached *Foldit* using the players' perspective and focusing on their experiences and identities. A discussion of the third aspect of leisure proposed for this issue, the socio-economic context, would require a more structural approach. In productive terms, there are major issues involved with a *Foldit*-type approach to doing science. Proteins that can help treat illness are big business for pharmaceutical companies, and for scientific reputations. Such a critical analysis could be grounded in the burgeoning literature on digital labor (see Scholz 2012), and would stress that, beyond its attractiveness as a leisure activity, *Foldit* harnesses the voluntarily provided labour of game players, and its structure organizes this activity to enable treatment by mathematical models and computing power in the emerging trend of data-driven science.

In the context of leisure studies, further research could explore the different strategies *Foldit* players employed in negotiating the constraints imposed by the NewChapter update. A more longitudinal study could provide insight into specific strategies, the ebb and flow of participation, as well as the relationship between motivation to negotiate constraints and individuals' belief in their performance capabilities and competencies.

References

Armstrong Moore, Elizabeth. 2011. "Foldit game leads to AIDS research breakthrough." *CNETNews*. Accessed January 17, 2015. http://news.cnet.com/8301-27083_3-20108365-247/foldit-game-leads-to-aids-research-breakthrough/

Barley, Stephen R. and Beth A. Bechky. 1994. "In the Backrooms of Science: The Work of Technicians in Science Labs." *Work and Occupations: An International Sociological Journal*, *21* (1): 85-126.

Bohannon, John. 2014. "Online Video Game Plugs Players Into Remote-Controlled Biochemistry Lab." *Science. 343*(6170): 475. Accessed January 17, 2015. *doi:* 10.1126/science.343.6170.475 http://www.sciencemag.org/content/343/6170/475.summary

Bos, Nathan, Ann Zimmerman, Judith S. Olson, Jude Yew, Jason Yerkie, Erik Dahl, Gary M. Olson. 2007. "From Shared Databases to Communities of Practice: A Taxonomy of Collaboratories." *Journal of Computer-Mediated Communication* 01/2007; 12:652-672. doi: 10.1111/j.1083-6101.2007.00343.x

Charvolin, Florian. 2004. "Le programme Feederwatch et la politique des grands nombres." *Développement durable et territoire*. Accessed January 17, 2015. http://developpementdurable.revues.org/687 ; DOI : 10.4000/developpementdurable.687

Cho, Adrian and Daniel Clery. 2009. "Astronomy Hits the Big Time." *Science*, *323*(5912): 332335. http://dx.doi.org/10.1126/science.323.5912.332

Cooper Seth, Firas Khatib, Adrien Treuille, Janos Barbero, Jeehyung Lee, Michael Beenen, Andrew Leaver-Fay, David Baker, Zoran Popović and Foldit Players. 2010. "Predicting protein structures with a multiplayer online game." *Nature* 466: 756-760.

Cooper, Seth, Adrien Treuille, Janos Barbero, Andrew Leaver-Fay, Kathleen Tuite, Firas Khatib, Alex Cho Snyder, Michael Beenen, David Salesin, David Baker, Zoran Popović, >57,000 Foldit Players. 2010. "The Challenge of designing scientific discovery games." In *FDG'10, Proceedings of the Fifth International Conference on the Foundations of Digital Games* (p. 40-47) June 19-21, Monterrey, CA. USA. doi: 10.1145/1822348.1822354

Cooper, Seth. 2011. "A Framework for Scientific Discovery through Video Games." PhD diss. University of Washington. Accessed on the ProQuest ProQuest database. (3501867).

Csikszentmihalyi, Mihaly. 1990. *Flow: The psychology of optimal experience.* New York: Harper & Row.

Deterding, Sebastian, Dan Dixon, Rilla Khaled, and Lennart Nacke. 2011. "From game design elements to gamefulness: defining 'gamification.'" *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*. New York: ACM, p. 9-15. Edwards, Richard, 2014. "The "Citizens" in Citizen Science Projects: Educational and Conceptual Issues." *International Journal of Science Education, Part B*, 4(4): 376–391. doi: 10.1080/21548455.2014.953228

Glaser, Barney and Anselm Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Chicago: Aldine Publishing Co.

Godbout, Jacques. 1986. "La participation: instrument de professionalisation des loisirs." *Loisir et Société / Society and Leisure*, *9*(1): 33–40. doi: 10.1080/07053436.1986.10715249

Good, Benjamin, and Andrew Su. 2011. "Games with a scientific purpose." *Genome Biology* 12: 135. Accessed January 17, 2015. http://genomebiology.com/2011/12/12135.

Groh, Fabian. 2012. "Gamification : State of the Art Definition and Utilization." *Proceedings of the 4th seminar on Research Trends in Media Informatics. Institute of Media Informatics*. Ulm University. p. 39-46. Accessed January 17, 2015. http://vts.uni-ulm.de/docs/2012/7866/vts_7866_11380.pdf#page=39

Kawrykow, Alexander, Gary Roumanis, Alfred Kam, Daniel Kwak, Clarence Leung, Chu Wu, Eleyine Zarour, Phylo players. 2012. "Phylo: A Citizen Science Approach for Improving Multiple Sequence Alignment ." *PLoS ONE* 7(3): e31362. doi: 10.1371/journal.pone.0031362

Kelling, Steve, Jun Yu, Jeff Gerbracht, and Weng-Keen Wong. 2011. "Emergent Filters: Automated Data Verification in a Large-Scale Citizen Science Project." *In 2011 IEEE Seventh International Conference on e-Science Workshops (eScienceW)* (p. 20 27). http://dx.doi.org/10.1109/eScienceW.2011.13

Kelty, Christopher and Aaron Panofsky. 2014. "Disentangling Public Participation In Science and Biomedicine." *Genome Medicine*. 6:8 Accessed January 17, 2015. http://genomemedicine.com/content/6/1/8

Kennelly, Millicent, Brent Moyle, and Matthew Lamont. 2013. "Constraint Negotiation in Serious Leisure." *Journal of Leisure Research, 45*(4): 466-484.

Khatib, Firas, Seth Cooper, Michael D. Tyka, Kefan Xu, Ilya Makedon, David Baker, Foldit Players. 2011. "Algorithm discovery by protein folding game players." *Proceedings of the National Academy of Sciences, 108*(47): 18949-18953.

Lievrouw, Leah A. 2010. "Social Media and the Production of Knowledge: A Return to Little Science?" *Social Epistemology, 24*(3): 219-237. http://dx.doi.org/10.1080/02691728.2010.499177

Marshall, Jessica. 2012. "Victory for crowdsourced biomolecule design." *Nature News*. Accessed January 17, 2015. http://www.nature.com/news/victory-for-crowdsourced-biomolecule-design-1.9872

Miller-Rushing, Abraham, Richard Primack, and Rick Bonney. 2012. "The history of public participation in ecological research." *Frontiers in Ecology and the Environment, 10*(6): 285–290. http://dx.doi.org/:10.1890/110278

Morse, Janice. 1994. *Critical Issues in Qualitative Research Methods*. Thousand Oaks: Sage.

Nielsen, Michael. 2012. *Reinventing Discovery: The New Era of Networked Science*. Princeton: Princeton University Press.

Nicholson, Scott. 2013. "Two paths to motivation through game design elements: reward-based gamification and meaningful gamification." *iConference 2013 Proceedings*, p. 671-672.

Nov, Oded, Ofer Arazy, and David Anderson. 2011. "Dusting for science: motivation and participation of digital citizen science volunteers." In *Proceedings of the 2011 iConference* (p. 68–74). New York, NY: ACM. http://dx.doi.org/10.1145/1940761.1940771

Nov, Oded, Ofer Arazy, and David Anderson. 2014. "Scientists@ Home: What Drives the Quantity and Quality of Online Citizen Science Participation ?" in *PLoS ONE* 9(4): e90375.

Paharia, Rajat. 2013. *Loyalty 3.0. How to Revolutionize Customer and Employee Engagement with Big Data and Gamification,* New York: McGraw Hill Education.

Paillé, Pierre. 1994. "L'analyse par théorisation ancrée." *Cahiers de recherche sociologique, 23*: 147-181.

Prestopnik, Nathan and Kevin Crowston. 2011. "Gaming for (Citizen) Science. Exploring Motivation and Data Quality in the Context of Crowdsourced Science Through the Design and Evaluation of a Social-Computational System." ESCIENCEW '11 Proceedings of the 2011 IEEE Seventh International Conference on e-Science Workshops, p. 28-33. doi : 10.1109/eScienceW.2011.14

Raddick, M. Jordan, Georgia Bracey, Pamela L. Gay, Chris J. Lintott, Phil Murray, Kevin Schawinski, Alexander S. Szalay, Jan Vandenberg. 2010. "Galaxy Zoo: Exploring the Motivations of Citizen Science Volunteers." *Astronomy Education Review, 9*(1), 010103. doi: 10.3847/AER2009036

Scholz, Trebor (Ed.). 2012. *Digital labor: The internet as playground and factory*. London: Routledge.

Schrope, Mark. 2013. "Solving tough problems with games. Online communities are using the power of play to solve complex research problems." in PNAS, Proceedings of the National Academy of Sciences of the United States of America. 10(18): 7104-7106. Accessed January 17, 2015. http://www.pnas.org/content/110/18/7104.full doi: 10.1073/pnas.1306643110

Stebbins, Robert A. 1982. Serious leisure: A conceptual statement. *Pacific Sociological Review, 25*(2): 251-272.

Stebbins, Robert. A. 1992. *Amateurs, Professionals, and Serious Leisure*. Montreal, QC and Kingston, ON: McGill-Queen's University Press.

Stebbins, Robert A. 2001. "Volunteering - Mainstream and Marginal: Preserving the Leisure Experience." In M. Graham & M. Foley (Eds.), *Volunteering in Leisure: Marginal or Inclusive?* (Vol. 75, pp. 1–10). Eastbourne, UK: Leisure Studies Association.

Stebbins, Robert A. 2007. *Serious Leisure: A perspective for our time*. New Brunswick, NJ: Transaction.

Stebbins, Robert A. 2012. *The Idea of Leisure: First Principles*. New Brunswick: Transaction Publishers.

Wiggins, Andrea, Greg Newman, Robert D. Stevenson, and Kevin Crowston. 2011. "Mechanisms for Data Quality and Validation in Citizen Science." *ESCIENCEW '11: Proceedings of the 2011 IEEE Seventh International Conference on E-science Workshops*, p. 14–19. http://dx.doi.org/10.1109/eScienceW.2011.27

Wiggins, Andrea and Kevin Crowston. 2015. "Surveying the citizen science landscape." *First Monday*, 20(1) 5 January 2015 Accessed January 17, 2015. doi: http://dx.doi.org/10.5210/fm.v20i1.5520

Zichermann, Gabe and Jocelin Linder. 2013. *The Gamification Revolution: how leaders leverage game mechanics to crush the competition*. New York: McGraw Hill Education.

Notes

1 We had initially planned to recruit at least 15 participants, with varying profiles. However, the interview period coincided with a CASP event, which radically reduced the availability of committed players. In fact, a number of participants who had initially agreed to speak with us withdrew citing lack of time due to their involvement in CASP.

2 Names of players interviewed have been changed to protect anonymity, but the names of people taking part in online exchanges have been retained since the context is public. Some interviews were conducted in French or Spanish, and some quotes have been translated.

3 A third component of players' identities, not explored here, is their sense of belonging to the Foldit community. This is evidenced by the variety of active discussion spaces on the platform, resources such as Wikis and recipes made available to others, as well as by references to the community in players' discourse. Players who play in teams may also identify strongly with their Foldit team.