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Homo Politicus meets *Homo Ludens*: Public participation in serious life science games

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Abstract
Public participation in science and gamification of science are two strong contemporary trends, especially in the area of emerging techno-sciences. Involvement of the public in research-related activities is an integral part of public engagement with science and technologies, which can be successfully achieved through a participatory game design. Focusing on the participatory dimension of educational games, we have reviewed a number of existing participation heuristics in light of their suitability to characterize available mobile and browser science games. We analyzed 87 games with respect to their participatory and motivational elements and demonstrated that the majority of mobile games have only basic participative features. This review of the landscape of participative science games in the domain of life sciences highlights a number of major challenges present in the design of such applications. At the same time, it reveals a number of opportunities to enhance public engagement using science games.

Keywords
gamification, life sciences, public participation, serious games, synthetic biology

1. Introduction

Iain M. Banks' 1988 science fiction novel *The Player of Games* presents an idea in its extreme: a society where the outcome of a game determines the access to ultimate power. While winning totalitarian power through any means is better left to fictional novels, we explore the question whether games could indeed be used to enhance democratic deliberation and public participation in decisions affecting current and future generations. In this article, we attempt to find out whether, and to what extent, public participation can be realized via science gamification.

The Merriam-Webster (2014) online dictionary defines participation as an act of participating, which in turn means "to be involved with others in doing something: to take part in an activity or event with others" and also "to take part in something" and "to have a part or share in something." In the context of politics, the term is narrowed down to the information, consultation, and involvement of the population that is concerned by certain decisions (Goldschmidt, 2014).

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Table 1. "Ladders" of participation (derived from Arnstein, 1969; Biggs, 1989; Farrington, 1998; Goldschmidt, 2014: 61–63; Lawrence, 2006; Pretty, 1995; Pretty et al., 1995).

Categories of participation \ Author	Arnstein	Biggs	Pretty	Farrington	Lawrence	Goldschmidt
Non-existent Low	Manipulation Therapy	Contractual	Manipulative Passive			Transparency
	Informing					Information
	Consultation	Consultative	By consultation For material incentives	Consultative	Consultative	Dialogue
Medium	Placation					
	Partnership	Collaborative Collegiate	Functional Interactive	Functional Empowering	Functional Empowering Transformative	Involvement[a]
	Delegated power					
High	Citizen control		Self-mobilization			

[a]In German "Mitwirkung."

Goldschmidt (2014: 50) illustrates all criteria to differentiate between forms of participation and also to differentiate participation from other similar types of interaction. A major criterion to categorize these approaches is the depth, or degree, of participation. This is often described in a hierarchical (Arnstein, 1969; Biggs, 1989; Farrington, 1998; Goetz and Gaventa, 2001; Goldschmidt, 2014: 61–63; Lawrence, 2006; Pretty, 1995; Pretty et al.,1995), seldom in a non-hierarchical manner (Davidson, 1998). Table 1 gives an overview of these typologies.

Another way of categorization is emphasizing the communication aspects of participation, the theoretical background of the project, or the objectives of the participation process (Reed, 2008; Rowe and Frewer, 2000, 2005).

The criteria mentioned above can easily be transferred to the topic of participation in decision-making about science and technology, as many formats of participation have been carried out in the context of emerging technologies (Bogner, 2010; Fiorino, 1989; Goldschmidt, 2014; Stirling, 2008).

In all formats, especially in those where a selection of participants is needed (Fish et al., 2011; Rowe and Frewer, 2005), the decision has to be made whom to include in the endeavor. In biotechnology, after the "lessons learned" from genetically modified organism (GMO) debates, there has been a call to include a broad public into deliberative processes (Marris and Rose, 2010). These processes should be designed to overcome the problems of traditional ELSI (Ethical, Legal, and Social Issues) research, which was more concerned with downstream consequences of techno-scientific developments.

The demand for upstream engagement refers to the question, at what stage of the research and innovation process should participation take place. It is obvious that this question assumes a linear model of innovation or at least linear aspects of a more systemic change (Freeman, 1996; Godin, 2006). Beyond considerations of "demand-pulls" and "science-pushes," and the disruptive or incremental nature of innovation or diverse feedback loops, there is an agreement about the necessity of an early or upstream engagement in the flow of events that determine or constitute innovation (Marris and Rose, 2010).

Engagement employs participation on different levels in scientific processes: from defining a study question, gathering information and resources, developing hypotheses, designing methodologies, to collecting and analyzing data, interpreting the results, and disseminating and discussing the study outcomes (Bonney et al., 2009). Examples of such participation are numerous online and offline activities contributing toward biomedical research (f.e. 23andMe[1]), astrophysics and biology (Zooniverse[2]), linguistics (Wordrobe[3]), nature studies (Citizen Sort[4]), and many more.

Kelty and Panofsky (2014: 8) suggest seven dimensions of participation, used for characterizing participation endeavors in science and biomedicine, with an emphasis on web-based projects:

- Educational dividend: learn something valuable, especially participation itself;
- Goals and tasks: do not only undertake tasks but also help to set goals;
- Resource control: get to control (own or use) resources, not merely produce them;
- Exit: have the capacity to leave without penalty and with resources;
- Voice: opportunities to give feedback in order to influence outcomes;
- Visible metrics: empirical proof that participation is linked with the outcomes of the project;
- Affective/communicative capacity: opportunities to communicate among the participants to produce affect, affiliation, and sociability.

The dimensions partly describe aspects of the depth of participation as characterized above. Resource control corresponds to empowering participation, voice to consultation, and educational dividend to information. The goals and tasks variable refers to the stage of involvement of the participants as described by the linear innovation model. Although we are not in line with the rigor of Kelty and Panofsky's research, we consider their dimensions as a good complement to the ideas of Goldschmidt as well as of Rowe and Frewer, especially for the investigation of computer-based participatory approaches.

Participation in science games

Participation in science experiences growing popularity, thanks to the availability of computer technologies that make it easy to overcome temporal and spatial restrictions and involve people from different parts of the world (Kloetzer et al., 2013; Tang et al., 2013). Serious games narrow to a certain extent a gap that divides citizens contributing to science and technology and an immense world gamer community. Such games vary from small mobile games to online single- or multiplayer browser games to massive multiplayer citizen science games that involve hundreds of thousands of players from all over the world. The latter combine the manifold experience of diverse audiences with an entertaining game environment.

Science games present an alternative form of public involvement, contributing a constantly increasing amount of data and growing community of players. Such games as FoldIt, EyeWire, Phylo, or Zooniverse projects have already proven to make a significant contribution into scientific discovery and knowledge acquisition (Cooper et al., 2013; Khatib et al., 2011; Schrope, 2013; Tuite, 2014). Making the best of beneficial effects of science games depends on the players' engagement with them. Motivators, present in games, help players stay focused on the gameplay and to a large extent define the learning outcome (Ryan et al., 2006; Skalski et al., 2012). However, not only the number of motivators but also their "quality" plays an important role in engagement with a game, as we will demonstrate in our study.

There are numerous definitions of serious (science) games, which can be generalized to the following statement: serious games are games used for non-entertainment purposes in different fields, such as management, health care, and science (Susi et al., 2007; Zyda, 2005). Important characteristics of these games include subordination of the educational component to the story and integration of the entertaining component, which makes sense in the context of the story (Dunleavy et al., 2009; McClarty et al., 2012; Zyda, 2005).

Mayo (2007) outlined several features of serious games that make them especially effective in the field of education, such as learning by doing, goal setting, cooperation, continuous feedback, self-efficacy, and inquiry-based learning. However, playing serious games is not always beneficial for the learning process. Iten and Petko (2014) acknowledge that fun, an inherent characteristic of serious games, may be rather distracting for knowledge acquisition (Iten and Petko, 2014; Kirriemuir and McFarlane, 2004). They attribute this to the additional cognitive load the player experiences while playing the game. Moreover, Girard et al. (2013) point to the fact that the majority of the studies attempting to prove the efficiency of the game-based approach suffer from a number of limitations, such as a lack of a control group or inconsistency in the serious game definition. However, the beneficial impact of serious games can still be realized through increased attention to the game's subject, wider variety of interactive features in comparison with conventional learning, and the ability to engage players for longer periods of time, thus maintaining motivation and engagement with the learning process itself.

Elverdam and Aarseth developed a model for game classification that contains such categories as "Space" (physical and virtual), "Time" (internal and external), "Player" (relation and composition), "Game State," and "Struggle" (with "Challenge" and "Goal" dimensions) (Aarseth et al., 2003; Elverdam and Aarseth, 2007). Such dimension as "Player" incorporates to some extent the notion of game participation. The essence of games as an informal educational environment creates an ambience for participation and allows for a wide variety of learning outcomes, based on personal characteristics of players. As stated by Honey and Hilton (2011), various forms of participation could support different learning goals, be it deep expertise acquisition or simply raising interest in a certain topic.

2. Objectives

Although there are many concepts for characterizing participation and an abundance of studies on gamification, there is a gap in the literature as regards the link of the two, particularly with a focus on the gamification of science. Participation in science, or in technology assessment, often relies on traditional face-to-face methods, where engagement of the public with the topic is crucial for a productive discussion. Therefore, one might ask whether the potential of gamification could be used fruitfully to stimulate public dialogue due to the high motivational power of computer games.

The research question that drove this study was, "What characteristics of popular serious games make them an appropriate platform for public participation in life-science-related research and development?"

The objectives of this study were as follows:

- To review existing web-based and mobile life-science-related computer games;
- To analyze the games within the context of participation;
- To find potential facilitators for the development of new participative games in the field of the life sciences.

3. Sample

The purpose of our study was to investigate the dimension of public involvement in the domains of synthetic biology and responsible research and innovation (RRI) by means of playing serious games. We assessed 87 serious games from the field of life sciences, identified on Android Google Play, in the Apple App Store, and on the Science Game Centre[5] using the search terms "biology," "synthetic biology," "DNA," "cell," and "life." These libraries were chosen as the most popular sources of games offering the easiest access for the users of mobile devices. Of the 87 analyzed apps, 77 were free. We excluded all paid browser games from the sample. In all, 66% (58) of the games were mobile games, 33% (28) were browser games, and one game was available on both platforms. Totally, 94% (82) of the games needed no specific background information for playing them, whereas the games that required previous knowledge (5) were represented solely by quizzes.

4. Methods

To obtain a rich description of serious games in the context of participation in life science, we conducted an extensive literature analysis and retrieved the variables characterizing various aspects of public participation, motivation as well as technical and game-play-related features of games. We limited our analysis to the following variables that provide exhaustive characteristics of the games but do not overlap (Supplementary Appendix 1).

Tools to motivate the players include "Achievement," "Socializing," "Immersion," "Luck," and "Free lunch" categories. They are derived from a study performed by Yee (2006) on the motivation of players in MMORPGs (massive multiplayer online role-playing games), but they can be extended to games in general.

Our classification of the games ("Genre," "Platform," "Game vs Play") is based on the information provided by the game developers.

The variable "Time of participation" characterizes the stage of the research and innovation process as described in the much-criticized linear model (Freeman, 1996). The values of the variable are "Agenda setting (framing)," "Basic research," "Applied research," and "Prototyping."

The variable "Depth of participation" was derived from the theories of political participation described above (Table 1).

Of all the dimensions offered by Kelty and Panofsky (2014), we use only the "Resource control" and "Communication" variables, which supplement the previous categories. The levels of this variable were assigned a score from 0 to 5 depending on the direction of communication in the game: for example, the games scoring "0" provided information to the player within the pre-programmed gameplay, but the games scoring "4" and higher allowed for an "open-ended" scenario depending on the player's findings.

The characteristics of the motivators (derived from dichotomous and Likert scales, see Supplementary Appendix 1 available at pus.sagepub.com) were mainly used to determine the presence or the absence of the motivators (i.e. the presence of a motivator independently of its Likert value was recorded as 1, the absence as 0).

5. Results

The genres of 87 analyzed games are shown in Table 2.

The main category of analyzed games was action. The total percentage of games that feature action as their first component was 50.4%; puzzle, 16.1%; simulation, 16%; quiz, 9.2%; strategy, 3.4%; and adventure, 2.3%. About 2.3% of the analyzed games were classified as action/adventure/puzzle.

The highest level of participation was found in puzzle games. The lowest level of participation was found in all mixed-genre games, as well as in quizzes and adventure games. At the same time,

Table 2. Game genres of serious life science games ($n = 87$), %.

	Action (A)	Puzzle (P)	Simulation (Si)	Quiz (Q)	Strategy (St)	Adventure (Ad)	Total %
Action (A)	37.9	3.4	5.7			3.4	50.4
Puzzle (P)		16.1			1.1		16.1
Simulation (Si)		1.1	13.8				16
Quiz (Q)				9.2			9.2
Strategy (St)					3.4		3.4
Adventure						2.3	2.3

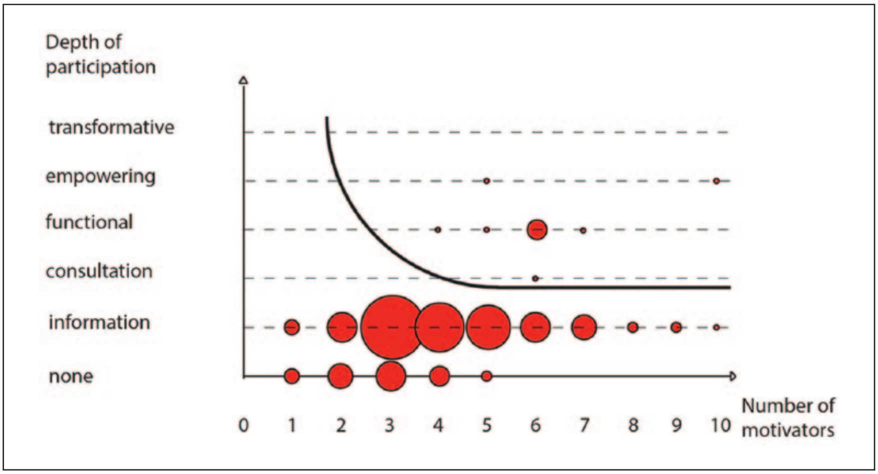

Figure 1. Results of cross-tabular analysis ($n = 87$): Depth of participation and Index of Motivators.

the participatory component of action games was the lowest among all analyzed games. Some achievement motivators like Levels, Bonuses, and Points as well as immersive elements are present in many games, whereas the absence of many socializing motivators is striking. The most used motivators in analyzed games were Points (found in 70.9% of the games), Levels (60.5%), Story Line (41.9%), Cascading Information during the entire game (37.2%), Linear Exploration (33.7%), Infinite Gameplay (32.6%), Bonuses (30.2%), and Quests (27.9%). The rest of motivators were found in less than 20% of the games.

The results of a cross-tabular analysis of the variables' depth of participation and a cumulative index of all motivating functions in the games are shown in the Figure 1.

The area of interest for this study comprises the games with a high number of motivators that are characterized by a high level of participation (upper right quarter of the diagram). Focusing primarily on the high level of participation, we have conducted a correlation analysis to investigate the relation between the depth of participation and the number of motivators. We revealed that the Spearman's rho was .459 (highly significant, with $p<0.001$). As such, there is indeed a positive correlation between higher levels of participation and increased number of motivators in such games (Figure 1). Only 10 games are in an area of interest involving high motivation and depth of participation.

Table 3. List of the games with high motivation and depth of participation.

Name	Genre	Motivators (range from 0 to 10[a])	Depth of participation (range from 0 to 5)	Platform	Gameplay[b]
EteRNA	Puzzle	10	4	Browser	Game
Phylo	Puzzle	7	3	Browser	Game
Play to cure	Action/Simulation	6	3	Mobile	Game
Forgotten Island	Adventure	6	3	Browser	Game
The Cure	Strategy	6	3	Browser	Game
FoldIt	Puzzle	6	3	Browser	Game
Pandemic	Simulation	6	2	Browser	Game
EyeWire	Puzzle	5	4	Browser	Game
Project Noah	Simulation	5	3	Mobile	Play
Happy Match	Puzzle	4	3	Browser	Game

[a]In theory, a maximum of 18 points would have been possible since we identified 18 different motivators. No game, however, presented more than 10 motivators at the same time.
[b]For an explanation of the two Gameplay variables Game and Play, see text.

The radius of the circles is proportional to the absolute number of games in one category with the largest one representing 13 games and the smallest ones only 1 game. The line separates the area of interest: high motivation and deep participation.

A cross-tabular analysis of the gameplay versus the depth of participation shows that only one game that ranks above "information" on the depth of participation scale is play-based, whereas all the rest of the more participatory games are totally game-based (Table 3).

The distribution of the time of participation (or phase of techno-scientific development) shows that both basic and applied research are the two predominant categories, whereas in agenda setting no game was found and in prototyping only one game was found. In all, 25.3% of the games could not be categorized within this scheme.

For Kelty and Panofsky's model of participation, the majority of the games (95.3%) did not provide any opportunities for communication. Only a few games allowed for communicating in the game and in and outside of the game (2.3% both). Access to the game resources (in the form of photos taken by the project participants) was provided only by one game (1.2%), and the rest of the games did not make any resources available.

The average number of downloads for the 10 games found in the area of interest was 2,131,250 (median: 150,000; data available for 8 out of 10 games), the average for the rest of the games was 2,446,284 (median: 1000; data available for 25 out of 77 games). The data provide a rough estimate due to the lack of available information for all games (Supplementary Appendix 2).

6. Discussion

This study was focused primarily on games for mobile devices and a limited number of the most popular browser games. Such a choice was determined by the fact that mobile technologies provide an especially wide variety of interaction opportunities. According to Jones et al. (2007), wide spread of mobile devices, their high functionality, constantly increasing processing capabilities and communication possibilities, relatively low cost, small size, and high portability provide an attractive opportunity to expand their use above and beyond simple communication purposes.

Using mobile devices to communicate science and engage the public in learning by playing provides an alternative approach to conventional ways of science communication. Encompassing such features of mobile devices as instant access to the Internet, ability to handle incoming calls and messages without impacting other applications, and incorporation of accelerometer or haptic feedback has a huge potential for creating an excellent player experience along with the correct presentation of scientific facts and an engaging gameplay (Collins, 2005). Scientific projects, based on the participatory approach, may also notably benefit from applying mobile technologies to solve certain tasks.

Games with a high number of motivators and a high level of participation could be particularly successful in attracting public interest to research and development in the life sciences (see Supplementary Appendix 2) because a presence of motivators increases engagement with the game, which helps retain players (Skalski et al., 2012). Such games can efficiently engage players, maintain their interest in participation, and contribute to solving a certain scientific task. As demonstrated by our analysis, only 10 games are found in the area of interest (combining the highest levels of participation with a significant number of motivators) of the cross-tabular analysis (Figure 1). However, the analyzed mobile phone games lack a number of features in order to be truly participatory science games. Only two mobile games were presented in the area of interest. Table 3 ranks the analyzed games depending on the number of motivators and the level of participation they have.

The highest levels of participation, namely, Functional and Empowering, were found almost exclusively in browser games: EteRNA, Phylo, Forgotten Island, Happy Match, The Cure, FoldIt, EyeWire, and Pandemic 2. The mobile games characterized by the highest levels of participation were Play to Cure and Project Noah. The following discussion provides an insight into the special features that make these games achieve high scores both in participation and motivation.

EteRNA (Carnegie Mellon and Stanford Universities, USA)

EteRNA puzzle game provides an opportunity to create a large-scale library of synthetic RNA. The players learn the basic principles of RNA structure and can create experimental RNA designs with novel functionalities. The game objectives include folding the molecule into a target shape or tinkering about with the molecule to create a new conformation with unknown properties. EteRNA allows for using experimental lab data in order to create new solutions for real-life puzzles and test them.

EteRNA has a tutorial level and ensures continuous feedback that guides the players through the learning process. Moreover, beginners benefit from a community support and interactions with numerous advanced players, who can submit their own puzzles.

Playing the game helps participants understand fundamental cellular processes and allows them to contribute toward developing and testing hypotheses that explain unknown properties and functions of RNA. The players use the computational power of their computers to solve RNA puzzles and contribute toward the development of novel biomolecules in a faster way than computer programs.

Phylo (McGill Centre for Bioinformatics, USA)

Phylo is designed as a puzzle game for multiple sequence alignment optimization in phylogenetics. The players need to match patterns of colored blocks that represent nucleotide sequences of different organisms. They aim for the highest possible score, which corresponds to the best match of color blocks with the smallest possible number of gaps between them. The purpose of the game is to determine the nucleotide sequences of different organisms while comparing the sequences of the related species with their common ancestor. The number of organisms to be matched depends on the difficulty level and can vary from 3 to 10.

Matching the blocks, players work with real sequences, provided by the UCSC Genome Browser. This game employs human-based computation in order to improve the results obtained using a computer algorithm.

Forgotten Island (Syracuse University, USA)

Forgotten Island is a citizen science–based adventure game, aimed to attract citizen scientists to classify various species of animals, plants, and insects. It is designed to help biologists perform classification tasks while using the computational power of numerous participants. The players are asked to gather the photos, scattered across the whole island after a mysterious explosion of the island's lab, and re-classify the depicted species. The game combines participation in scientific research, and such classic adventure game features as exploration of unknown terrains or gathering items that might be needed at some point in time. In order to define taxa, scientists have developed special keys to describe different characteristics (e.g. spots or color) and their combinations in target organisms.

Such characteristics can be described using different states depending on their intensity or pronouncedness (e.g. "dark" or "light"). The characteristics may highly vary by taxon and allow for identification of a specific family up to sub-species. Based on such an approach, the players contribute to the production of a large amount of valuable data that can be used in a number of fields.

Happy Match (Syracuse University, USA)

Happy Match is similar to the Forgotten island game, produced by the same team of scientists and aimed at classification of moths, sharks, and rays.

The players are presented with a photo and asked a number of questions concerning the appearance of a specimen.

The Cure (Scripps Research Institute, USA)

The Cure is a puzzle game with the aim to create a complete genomics-driven predictor for breast cancer prognosis. For any type of breast cancer, there are numerous gene variations that define the development of metastases and treatment perspectives. Using real data from tumor samples, the players identify the patterns associated with metastasizing of tumors based on different gene activity.

The players are asked to classify the genes associated with cancer into one of two groups: "good" (allow the patient to survive longer than 10 years from the time of diagnosis) and "poor" (less than 10 years providing that no major intervention took place).

By creating different combinations of provided genes, the players contribute to building predictive patterns that will further be used for the creation of advanced algorithms for cancer prognosis. Such citizen participation is necessary because of the large amounts of available data, different strength of pattern expression, and a high combinatorial complexity: some patterns may include up to 25 different genes.

FoldIt (University of Washington, USA)

FoldIt is a puzzle game for protein folding. The players create different configurations of provided proteins with the aim to achieve the best possible configuration, which brings the highest score.

This process is computationally demanding and challenging: it is very difficult to predict all the folding possibilities on the way from a linear primary structure to complex three-dimensional tertiary structures.

Obtained configurations are tested by scientists and used for solving real-life problems in medicine, biology or bioinformatics, such as creation of designed proteins, advancements in environmental management, or new treatment of diseases. In 2011, an article titled "Crystal structure of a monomeric retroviral protease solved by protein folding game players" was published in the Nature Structural and Molecular Biology journal (Khatib et al., 2011), which described the development of a three-dimensional (3D) model of the enzyme by the FoldIt players.

EyeWire (MIT, USA)

Neuroscience-based game EyeWire documents 3D structure of neurons in a retina. The goal of the game is to create a precise map of a human connectome, the whole network of neurons and connections between them in the human brain, and to identify the synapses of any given neuron as well as to discover the relation of the activity of neurons and their connectivity. The original data are provided as photographs obtained by scanning electron microscopy. A player should trace a given neuron through a certain volume of brain tissue with the help of an artificial intelligence (AI) algorithm that assists in following the right parts of the neuron. The contribution of the players varies from filling in the missed by AI parts of a neuron missed by the AI algorithm to tracing whole branches of it.

Availability of a complete brain map is highly important for treatment of such cognitive disorders as Alzheimer disease, dementia, depressions, and other mental conditions, which development sped up over the last few years.

Play to Cure (Cancer Research, UK)

Play to Cure is an action–adventure game, designed to assist in breast cancer research. Players are asked to design and navigate their spaceship across the genome areas that potentially contain cancer-related mutations and collect an Element Alpha. The areas containing large amounts of this element are of special interest for the scientists: they may indicate the genome areas that contain many mutations.

Solving the problem of finding mutations-rich regions using computer software is complicated because of the lack of proper accuracy. The results delivered by numerous participants allow the scientists to reduce the number of the genome regions which need to be investigated.

Pandemic (Dark Realm Studios, Canada)

The simulation game Pandemic stands alone among the serious games we have analyzed due to its original way to interpret the participation in a serious game: the game provides the player an opportunity to create a disease and wipe the humanity out from the Earth. Players can manage their disease in multiple ways: modify or add new symptoms, ways to spread, resistances, life forms to infect, and so on. The advancement of the disease can be observed on the world's map.

Progression in the game is awarded with points that can be used to "upgrade" the pathogen and equip it with more damaging capacities.

Despite the fact that such an approach may seem rather controversial, we regard it as a very effective way to learn about epidemiology of infectious diseases, on one hand, and a great participative initiative, on the other. Tackling the challenges of infecting different countries, the players contribute to understanding the spread of diseases under varying circumstances and with respect to national and international regulatory measures.

Project Noah (Networked Organisms, USA)

Project Noah is a community-based platform to explore nature and assist scientists in documenting wildlife species. Players can join existing missions or create their own ones, dedicated to any possible specie or area of the world. They submit photos of wildlife organisms and request help from other participants to identify them or label them with the name, location, and time spotted before submitting.

Collaborations of citizen participants and scientists in the project allow for collecting ecological data as well as stimulating awareness about wildlife among school children. The ultimate goal of the project is rather ambitious: documenting all species existing on the Earth and helping to preserve biodiversity.

The review of 10 games with a high level of participation reveals a number of common features that decisively differentiate them from the rest of the analyzed games. As a general rule, in order to ensure high levels of participation, a game must be entertaining and enjoyable (Ryan et al., 2006; Skalski et al., 2012). As is evident from Figure 1, all the evaluated games that score high on the depth of participation score higher on the number of motivators as well, in comparison with the low-participation games.

A correlation analysis exploring the interrelation between the depth of participation and the number of motivators revealed that the Spearman's rho was .459 (highly significant, with $p<0.001$). As such, there is indeed a positive correlation between higher levels of participation and increased number of motivators in such games. As we do not have any hypotheses regarding this interrelation, this can only be a starting point for a more detailed hypothetical model or path analysis. Therefore, searching for possible mediators in this correlation and an argument for a causal direction would be impulses for future research.

Moreover, "participation" in science games implies "contribution" toward the goal set by a research institution, may it be data analysis (Play to Cure, FoldIt, or EyeWire) or direct contribution of materials (Project Noah). High quality of obtained data, as well as retention of participants, directly depends on the quality and the level of game engagement, which is defined by how motivated the players are (Crowston and Prestopnik, 2013). Along with the motivation, the games significantly lack socializing features, as mentioned before.

From Table 3, it may be concluded that despite the advantages of mobile technologies, browser games still provide more opportunities for interactive learning and participation in research. The prevalence of action games that lack any participatory traits among the serious mobile games suggests that this genre might be less appropriate for the purpose of two-way science communication in comparison with puzzles, simulations, or strategic games.

As demonstrated by the study of Phan et al. (2012), the preferred game genres for male players include strategy, role-playing, and action, whereas for female players those include puzzle and simulation. Moreover, female players prefer playing on mobile/handheld devices, whereas male players prefer classic computer games. Such pattern confirms earlier data, obtained by Bonanno and Kommers (2005), who found puzzle games and mobile devices more attractive for female than for male players. In the following study, they revealed further gender-related specifics of game engagement: male players felt more confident operating gaming devices and perceived gaming experience as more relaxing and positively contributing to future work. Moreover, they regarded games as a unique learning tool. The female players who participated in the study were less comfortable using hardware and less convinced in the uniqueness of educational experience provided by serious games. At the same time, both males and females perceived gaming as positive and socially accepted activity in general and regarded serious games as beneficial educational experience in particular (Bonanno and Kommers, 2008). The differences between female and male players can be explained by neuro-cognitive specifics of information processing: male players excel in competitive manipulation-oriented spatial tasks, whereas female players in social non-competitive verbal tasks. Based on these differences, the attitudes toward participation in games differ between males and females as well: male players tend to regard computer technology as a skill to be mastered, while female players consider it as a tool to perform a given task.

Based on this information, we can argue that for female players the primary interest lies in the game objective with the main task to reach the goal of the game. Instead, for male players the primary interest may lie in the game interface or interacting with the game, hence participation. Such vision of gaming could explain the preferable game design for different genders: non-competitive puzzles as a preferable genre for female players and competitive action for male players. The nature of analyzed games may discourage female players from equal participation in these games. Given the prevalence of action games, this suggests that the majority of participatory games are designed in a way that attracts predominantly male players.

7. Conclusion

The research question that drove this study was, "What characteristics of popular serious games make them an appropriate platform for public participation in life science-related research and development?"

The objectives of this study were as follows:

- To review existing web-based and mobile life science-related computer games;
- To analyze the games within the context of participation;
- To find potential facilitators for the development of new participative games in the field of the life sciences.

Our study allows us to isolate the following characteristics of analyzed games that are associated with a high level of participation: a variety of motivators (Supplementary Appendix 1), a high level of engagement with the game based on the number of players/downloads (Supplementary Appendix 2), the type of gameplay and socializing opportunities, represented by specific in-game tools as well as by the game genre.

Despite this, the development of games in the context of participation within life sciences was revealed to be a one-sided endeavor. The capacities of engaging people in participation using serious games for mobile devices are widely unused: the majority of the games we analyzed did not contain any participative features other than simply providing the players with some information about game tasks. The majority of analyzed life science games fully or partly belong to the genre of action, whereas the majority of the games scoring high for participation are puzzles or simulations. Although there is a high number of possible genres and genre combinations, they have not been explored to create more participative games. We argue that the success of purely entertaining games, designed predominantly in the action genre, should not be extrapolated to games that have a different purpose. Substituting a scientifically specific goal with a goal typical for an action game could be detrimental to the quality and scientific relevance of the game.

However, the game Play to Cure demonstrated that the action genre or action combined with another genre could also be utilized for designing an engaging participative game. As evident from our analysis, the success of this exception should encourage game developers to introduce more participative features in new life science games, not limiting themselves to browser games.

Socializing is one of the most important cornerstones of participation because it provides an opportunity for building up community, experiencing exchange, and participating in collective problem solving (Steinkuehler and Williams, 2006). Although functions for socializing in games could be typical for some genres, we find them lacking throughout all the science games, even at the lowest levels of participation, such as information. This problem concerns mobile games to a greater extent than browser games and provides a vast number of opportunities to enhance the socializing feature.

Such game characteristics as gameplay, along with socializing, are crucially important for the quality of learning outcome or reaching the scientific goal of the game (Fabricatore, 2007). A large number of mobile games, evaluated during this study, heavily relied on a game-based type of gameplay. Given that a lot of serious games enjoy high popularity among the public (Khatib et al., 2011), we see a certain potential for more play-based games to enter the stage of serious participative life science games. Such play-based games may routinely provide necessary raw data for further evaluation and editing as Project Noah or Play to Cure does. On the other hand, setting a goal and working toward its achievement, fundamental characteristics of the game-based gameplay, are lacking a meaningful implementation in many science games for mobile devices that we analyzed in this study.

The results of the analysis of the time of participation were particularly striking: games dealing with the planning and design of a research project, as well as the downstream prototype testing are not present. As such, the call for upstream engagement in RRI can also be taken for a call for games that are about these early stages of techno-scientific development.[6]

The limitations that may have had a potential influence on the results of our study include a limited sample of the games and game sources, a limited consideration of research areas other than bio-related, an absence of a fully validated scales for in-game motivators and game characteristics, a scheme of games classification, and the use of a rather synthetic classification of public participation from several sources.

Despite the potential limitations, our analysis of the top representatives of participative life science games allows us to give some recommendations for the development of new games in this field:

1. Explore genres and their combinations (other than puzzle and simulation) that can contribute scientifically meaningful results;
2. Go upstream: Games are an option not only for functional participation but also for participative and prospective technology assessment;
3. Further explore the possibilities of play-oriented games that deliver relevant information for further analysis;
4. Integrate such functionalities as in-game communication and other socializing motivators and go beyond the usual methods, such as points, bonus, and levels system of achievement motivators.

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Notes

1. https://www.23andme.com/
2. https://www.zooniverse.org/

3. http://wordrobe.housing.rug.nl/
4. http://www.citizensort.org/
5. http://www.sciencegamecenter.org/
6. See, for example, the recent conference in November 2015: Engaging Society in Responsible Research and Innovation: What's Next? Available at: http://engage2020.eu/media/Engage2020_programme.pdf

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