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The Role of Gamification in Participatory Environmental Sensing: A Study in the Wild

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ABSTRACT

Participatory sensing (PS) and citizen science hold promises for a genuinely interactive and inclusive citizen engagement in meaningful and sustained collection of data about social and environmental phenomena. Yet the underlying motivations for public engagement in PS remain still unclear particularly regarding the role of gamification, for which HCI research findings are often inconclusive. This paper reports the findings of an experimental study specifically designed to further understand the effects of gamification on citizen engagement. Our study involved the development and implementation of two versions (gamified and non-gamified) of a mobile application designed to capture lake ice coverage data in the sub-arctic region. Emerging findings indicate a statistically significant effect of gamification on participants' engagement levels in PS. The motivation, approach and results of our study are outlined and implications of the findings for future PS design are reflected.

ACM Classification Keywords

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

Author Keywords

participatory sensing; citizen science; civic technology; environmental sensing; human behavior; engagement; gamification

INTRODUCTION

The human-computer interaction (HCI) community has for long been investigating the role of digital technology in citizen participation [14, 25, 63, 22, 1] including its role in understanding the impact of environmental change and in supporting sustainable practices [32, 26, 31, 53]. Views that citizens can be persuaded into acting 'more sustainably' have also been challenged [25, 30] together with the reductionist view of the rational "Resource Man" adapting his/her behavior to data [54]. However, it is undeniable that technology has enabled citizen participation to far-reaching causes on a massive scale [7], offering the opportunity for a deeper understanding of the mechanisms underpinning societal and environmental changes not only at global, but also at local level [50, 64, 1, 28].

Participatory Sensing (PS) - often also referred as citizen science, crowd-sensing and crowdsourcing - is a form of civic technology designed to support public participation in the collection of meaningful, located data [27, 5]. Over the last decade, PS has gained popularity with applications such as eBird, Fold.it, Waze, Ushahidi, and Galaxyzoo; such tools have been actively supporting citizen-driven data collection for a varied of purposes including scientific research and crisis communication [16, 21], whilst serving as means for inclusive engagement, education, and public outreach [2, 24, 13]. Despite its widespread popularity, the motivations underlying citizen engagement are still unclear [39] and so is the role of gamification in this context [49, 39, 30]. In particular, it is still unclear how effective gamification is and in which PS contexts [24], highlighting the need for empirical studies [12, 23, 43, 52, 60].

The aim of this paper is to further investigate the role of gamification in citizen participation in PS through empirical observation. We do so by running a user study involving forty-one participants monitoring ice coverage of sub-arctic lakes. By using two versions (gamified and non-gamified) of a bespoke mobile app, we observe that the gamified version of the application has a statistically significant higher PS engagement than the non-gamified one. Engagement is here measured by the number of submitted observations. From the study qualitative feedback, we also note that an increased use of the application can have additional impact on participants' attitudes and behavior, including spending more time outdoor, becoming more appreciative of the local environment and how it changes over time.

The main contribution of this paper is a further insight into the role of gamification in PS. Specifically, we find that adding gamification to an environmental monitoring application significantly increases the number of participants' observations. This paper outlines the rational, approach and results of our study and reflects on implications for future PS design.

RELATED WORK

It is argued that *"environmental issues are best handled with the participation of all concerned citizens"* [58, 57, 56]. This is a result of the significant evolution of the relationship be-

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tween governments and citizens in the past 60 years from consciousness raising in the 1960s, the incorporation of local perspectives in the 1970s, the recognition of local knowledge in the 1980s, the participation as a norm as part of the sustainable development agenda of the 1990s, and the e-participation governance in the 2000s [57, 56, 47, 4, 64].

Technology has played a key role in the evolution of participation. The publics are now actively engaging with diverse causes via ICT (e.g. activism, mobilizations, public campaigning, community monitoring) [7]. In this context, systems such as participatory sensing (PS) - often also referred to as citizen science, crowd-sensing or crowdsourcing - have emerged as an opportunity to monitor social and environmental phenomenon in detail; since mobile technology has become pervasive and able to capture, classify and transmit location, image, voice and other data autonomously [49, 6, 16, 21]. *Participatory sensing is data collection and interpretation enabled by technology* [5, 21].

The data being submitted in PS represents a deliberative act of public participation by the interaction of the public with the technology-enabled services. In the early 2000s, city development, urban crime surveillance, and forest conservation were highlighted as promising applications of participatory sensing [45]. Over a decade later, the applications in those domains (among many others) have widely spread among the publics. For example, FixMyStreet [1] FixMyStreet allows citizens to report city issues e.g. broken pavement) to enhance city maintenance; Ushahidi[2] helped the Kenyan government in 2007 to map violent acts across the country and has been used in more than 10 countries since then; eBird[3] was launched in 2002 to gather basic data about bird distribution across the globe. By now eBird has collected hundreds of millions of observations from most countries in the world. Finally, Safecast [4] was launched by citizens' initiative to monitor the radiation levels in Japan after the nuclear accident in Fukushima in 2011. By now, it has become the largest monitoring network in the history of the planet.

PS systems are built based on public participation, but they also serve the public in solving daily problems (e.g. finding the best route home). Hence, citizens are found at these applications' very operational core for two main reasons: firstly, because of the way they are operated, any participatory sensing platform is doomed to fail if it has no participants; and secondly, because of the great value of local knowledge and the intimate understanding the public has on the patterns and anomalies in their communities. This local knowledge can complement expert assessments as it includes important contextual information [5]. Among the different challenges that PS holds (from technology leaps, privacy and security concerns to data quality and standardization), active public engagement remains a key challenge in this field.

[1]FixMyStreet: http://www.fixmystreet.com
[2]Ushahidi: http://www.ushahidi.com
[3]eBird website: http://www.ebird.org
[4]Safecast website: http://blog.safecast.org

However, the underlying public motivation to actively engage and participate in PS is still unclear [19, 15]. Particularly, the impact of gamification mechanisms on human behavior in PS remains under discussion: with current HCI findings [49, 39, 30, 17, 18] often inconclusive/contradictory and domain agnostic. For example, Knowles et al. [30] doubt that gamification works based on the claim that game elements activate negative achievement values which might not support pro-environmental behavior change. In the other hand, Ross [49], claims that pervasive games empower humans to take actions to improve society, and Massung et al. [39] argue that gamification can impact extrinsic motivators that enhance pro-environmental practices. Meanwhile, one of the most successful participatory sensing projects so far is Foldit [5], an online puzzle game which challenges participants to fold protein structures as perfectly as possible using the game tools. Scientists can analyze the applicability of the highest scoring solutions for curing diseases; it has been shown that the best Foldit players can match or exceed computational solutions [8]. By 2014 Foldit already exceeded 200,000 players [37, 59].

Given this context, gamification was selected as the method to study engagement, as it is a technique with a solid theoretical basis for impacting human behavior [52]. As such, gamification is the application of game-like elements to non-game environments [11]. It has also been defined as a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation [29]. Approaches that use some elements of gamification have been shown to increase user motivation and engagement in a variety of environments [52], including participatory sensing [42].

However, it is still not clear how well gamification works and in which contexts [23]. For example in citizen science, gamification has been used to encourage [38, 39, 36] and improve [66] participation. The results in these studies were positive [36] or inconclusive [38, 39, 66]. In yet another study from the field of sustainability gamification was used to engage customers with positive outcomes [20]. Therefore there have been calls for rigorous empirical studies to be performed to better understand the effects of gamification [12, 23, 43, 52, 60]. For these reasons, we carried out a user study in-the-wild to further understand the effects of gamification on human engagement and the perception in the context of environmental sensing.

METHODOLOGY

This study was aimed at understanding the effects of gamification on user engagement and user experience in a participatory sensing application. Both engagement and user experience were measured by quantitative indicators (see table 1). Nonetheless, it is important to highlight that a variable name might have a wider meaning in other contexts [67]. The user engagement was measured by three indicators:

- Involvement: Total number of submissions per user,

[5]Foldit website: http://www.fold.it

- Activeness: Number of active users from beginning to end of the study. In this context, an active user is understood as a user that submits observations in a daily basis.
- Dropout: Total number of users who left the study.

On the other hand, the user experience was measured in terms of:

- Effectiveness: Ratio of the number of submissions and application openings (per user),
- Learnability: Time to become familiar with the application at the first use,
- Satisfaction: Rates (in a five Likert scale) ease of use and usability satisfaction statements

Table 1. Variables and Indicators.

Variable	Indicator	Measurement
Engagement	Involvement	Number of submissions
	Activeness	Number of users who were active for the entire duration of the study
	Dropout	Number of who did not complete the study
User Experience	Effectiveness	Number of submissions per app usage
	Learnability	Time to learn the app during the first use
	Satisfaction	Survey-based opinion

During this study, the participants had to submit photos of the ice status of the largest lake in Finland (lake Saimaa) during a seasonal change. For this purpose, two applications were designed: a gamified application and a non-gamified application. Then, the participants were divided in two groups: a control group and an experimental group; and they were randomly assigned to use one of the applications for 20 days. The length of our study is limited by the time between the freeze-up and break-up of the lake Saimaa, which is typically about 4 months [33]. This sets a maximum observation time frame for the public to be able to perform monitoring.

Experiment Design

We designed our experiment following the guidelines of Wohlin et al. [67]. In our study, the independent variable was *gamification elements* and the dependent variables were *a) engagement and b) user experience*. Two hypotheses were defined in order to understand the effects of gamification on the dependent variables

1) Hypothesis for Engagement Variable:

- Null hypothesis $H0_1$: The use of gamified elements in a lake monitoring application produces equal or less user engagement than a non-gamified application.
- Alternative hypothesis $H1_1$: The use of gamified elements in a lake monitoring application produces a greater user engagement than a non-gamified application

2) Hypothesis for User Experience Variable:

- Null hypothesis $H0_2$: The use of gamified elements in a lake monitoring application produces the same user experience as a with a non-gamified application.
- Alternative hypothesis $H1_2$: The use of gamified elements in a lake monitoring application produces a better user experience than a non-gamified application.

Participants

The selection followed a non-probabilistic convenience sampling where invitations to participate were sent to university students through mailing lists. As a result, 41 volunteers (a person who carries and activity without being paid) signed up to participate in the experimental study which took place from 24 March to 12 April 2017 (20 days). After signing informed consent agreement, the participants were randomly divided into 2 group (see figure 1): a) the control group (20 participants) received a non-gamified application and, b) the experimental group (22 participants) received a gamified application. The participants received an instruction session before the start of the experiment. This session provided information about the experiment motives, data treatment, application functionality and answered their questions.

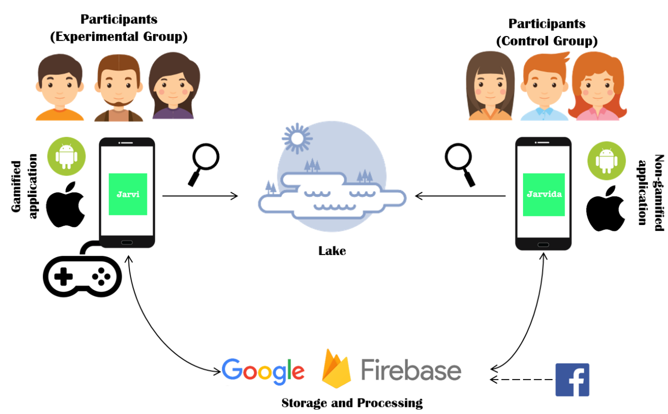

Figure 1. Participatory Sensing System Architecture.

System Design

In this study, two mobile applications - one non-gamified application and one gamified - were developed both for Android and iOS platforms. The architecture of these applications is presented in Figure 1. The development process was mainly designer-led with feedback of different versions of the systems collated from students and researchers.

Non-gamified application: Jarvida

Jarvida was a regular water bodies monitoring application, inspired from existing tools in use (such as Järviwiki[6], Finnish

[6] Järviwiki website: http://www.jarviwiki.fi

Hydrological Citizen Observation Network[7], CreekWatch[8]). The application logic was straightforward (Figure 2); it would start from providing some educational examples about ice types on a lake then, the participants could proceed to submit. The user had to select a location for this observation (so that the user would not be bounded to make a submission when the photo is taken but rather to be able to submit at any point of the day). Also, the submission could have an image attached or it could be just a report of the ice status, there were three observation values: no ice (water is not frozen), partially ice-covered (water is partially frozen or melted) and compactly ice-covered (water is compactly frozen and ice thickness can be measured). Finally the participant could, check the statistics about the ice status based on all the observations in his area. A use case example starts with the user logging in, then information about the ice types is displayed along some educational images. Next, the user can proceed to submit an observation and add locations along ice values. Finally, the user can see the statistics of ice condition in the area.

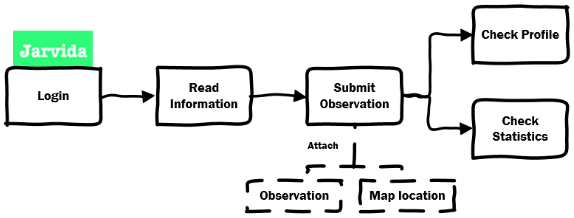

Figure 2. Jarvida logic

Gamified application: Jarvigo

Jarvigo provided the same features for environmental monitoring as Jarvida, but with game elements integrated. The gamification elements [68, 48] added to this version were as follows:

- Interactive map: All submitted observations appeared on the map as pins. Users could tap on the map to add a new pin or use an existing pin then, they could submit an observation. Pins would change of color (red to green) when a submission was done.
- Storytelling: A story describe the context of the task. Then it gives a mission that users need to accept (challenge). The story was designed to raise participant's awareness about environmental monitoring, and making users feel that their contributions make an impact to their community and the world.
- Challenge: Each observation task was seen as a challenge or mission that users needed to carry on for a specific period of time.
- Points: Points are the most basic but compulsory element in gamified systems. In this application, participants who submitted observations were rewarded the experience points (XP).

[7]Finnish hydrological citizen observation network website: http://www.kansalaishavainnot.fi/lumi

[8]CreekWatch website: http://creekwatch.ca

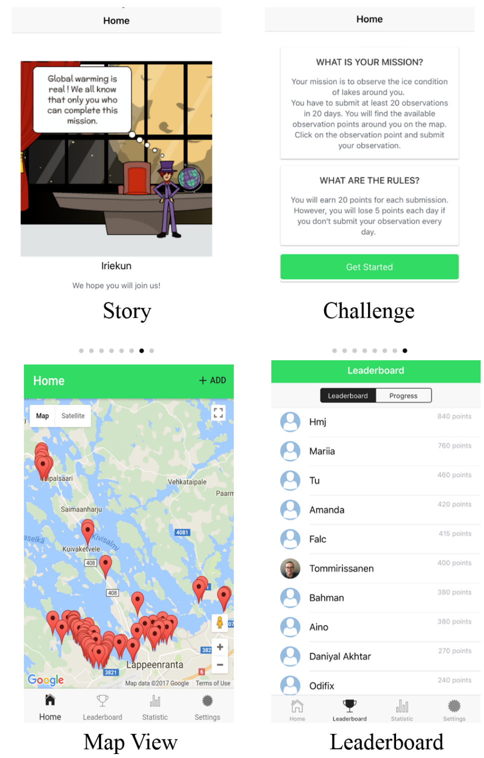

Figure 3. Gamification elements in Jarvigo app.

- Leaderboard: Participants were ranked according to their earned points. Top ten users were displayed in the leaderboard.
- Feedback: This technique was used to make users feel that their contributions were not taken for granted and it gave users the feeling of satisfaction from seeing their own progress and points earned.

The logic in Jarvigo (Figure 4), would start with a story related to global warming, highlighting the importance of lakes monitoring. Then it asks participants to accept a challenge (submitting 20 observations in 20 days). After accepting the challenge, participants could view a map of the area with all the pins where other observations have been submitted. Then, they could submit an observation by tapping on the location they have observed. Again for the submission the user could attach an image or just report the ice status (no ice, partially ice-covered and compact ice). When they submit an observation, 20 points are awarded. Participants could track their progress and see the top ten ranked participants (based on scores) on the leaderboard. Finally the participant could also check the statistics about the ice status in their area.

In order to balance the challenge effect among groups and avoid a "Hawthorne effect" (where participants modify their behavior simply because they are being observed) among the participants using the gamified application, participants who used the non-gamified application were recommended during the introductory meeting to use the application every day during the study duration (which was the equivalent of the goal in the gamified version).

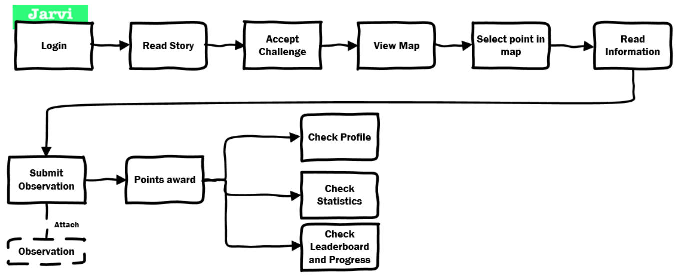

Figure 4. Jarvigo logic.

Analysis Method

The source data for this study came from the applications usage logs and pre- and post-questionnaires. Given the participant pool size, the independence of the test groups, the ordinal and non-normal nature of the dataset, Mann-Whitney U test [67] - a nonparametric test for independent samples - was used to calculate the statistical significance of the data sample and thus, reject or keep the null hypothesis.

The pre-[9] and post-[10] surveys were designed to collect quantitative and qualitative data regarding the perception and experience of the participants during this study. Standardized questionnaires such as the systems usability scale [3], the IBM computer usability satisfaction questionnaire[35], the user acceptance of information technology scale [62], and perceived playfulness questions [61]; were included in the pre- and post-questionnaires. The overall data collected was: participants' demographics and environmental interests and perceptions about user experience, usage habits, gamification features, enjoyment and playfulness.

FINDINGS

41 volunteers aged 20–35 participated in this study which lasted 20 days. Participants were randomly divided into two independent groups. Hence, there were 20 participants using non-gamified application (Jarvida) and other 21 participants using gamified application (Jarvigo). A total of 304 observations were submitted via both applications. A major concern during this period was the weather conditions as the temperature ranged between -8C°and 12C° and, participants had to record their observations outdoors. The findings in this section are presented by variable and indicators. These findings derive from statistical tests and descriptive statistics onto each one of the indicators (involvement, activeness, dropout, learnability, effectiveness and satisfaction). Also, to ensure data consistency and to avoid common issues in this type of applications (such as spam or duplicate submissions) [40], the dataset was checked for duplicated submissions (e.g. same observation submitted multiple times in order to gain points or by mistake).

Engagement

In this context, engagement refers to the number of observations submitted by participants (involvement), the level of activeness of the users from beginning to end in the study (activeness) and the number of participants abandoning the study (dropout). The overall results (see Table 2), show that the involvement and activeness among the participants who used the gamified application was significantly higher compared to the ones who used the non-gamified application. On the other hand, the dropout percentage was similar in both applications. Given this results, the null hypothesis is rejected and the alternative hypothesis is accepted *"$H1_1$: The use of gamified elements in a lake monitoring application produces equal or less user engagement than a non-gamified application."*. Each indicator and its results are explained below:

Table 2. Engagement Indicators: Results (where: n)not significant, **)statistically significant at p<0.05, *)statistically significant at p<0.01, ****)statistically significant at p<0.001).**

Indicator	Measurment	Non-gamified Jarvida	Gamified Jarvigo	Difference and significance
Involvement	Total submissions	44	260	216 ***
Activeness	Very Active users from beginning to end	17 %	50 %	33 % (N/A)
Dropout	Number of participants who did not complete the study	10 %	5 %	5 % (N/A)

- Involvement: The results show that the observations submitted in the experimental group (using the gamified application) was statistically significantly higher at than the control group (using the non-gamified application) (U=346; p=0.0003612; at p<0,001). Figure 5 shows the distribution of the submissions from both applications over time.

  There were a total of 304 submissions from both applications. From which, 44 observations came from the non-gamified application users (control group) and 260 came from the gamified application users (experimental group). Hence, the submissions from the gamified application were 71% higher.

  This result might be related with the user experience of participants. From the qualitative analysis of comments from participants in the post survey, we found that the participants who used the non-gamified application found the application easy to use and useful (e.g. *"It's easy to use and flexible"; "Satisfactory and useful for understanding the climate change"* (P15,P9)). While, the participants who used the gamified application found it easy to use, useful, interesting and fun (e.g. *"I found app very easy to use and effective way to get live data from different location. It was fun and a good experience to provide data for such cause."; "it was fun and desire to submit observations incentivized me to walk more: So I would say that it is useful not only for lakes, but for people as well."; "A great way to study such an important issue. Hopefully this will continue and I would participate also in the future."*(P20,P35,P1))

- Activeness: This indicator refers to the number of participants who were very active using the application during the study. There were 18 participants using the non-gamified application (from beginning to end), out of which, only three of them were very active users (submitting observations daily) corresponding to 17% of the group population.

[9] pre questionnaire: http://goo.gl/JJB5k2
[10] post questionnaire: http://goo.gl/8rk1sG

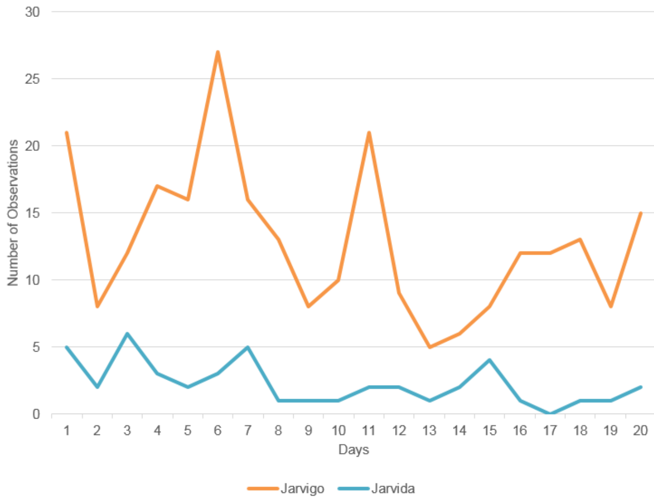

Figure 5. Submitted Observations per application over time.

On the other hand, among the 20 participants using the gamified application (from beginning to end), there were 10 very active participants corresponding to the 50% of its population.

- Dropout: The study started with 20 participants using the non-gamified application. Two of them did not complete the experiment to the end (dropout=10%). On the other hand, with the gamified application, there were 21 participants in the beginning, out of which 1 abandoned the study (dropout=5%). This result shows that there were not major differences in the dropout rate between the two applications.

User Experience:

In this study, the user experience refers to: the submissions completed when the applications were open (effectiveness), the time it took to the participants to understand their application (learnability) and the overall perceptions and satisfaction with their applications usability (satisfaction). The overall results (see Table 3), show that the effectiveness among the participants who used the gamified application was twice as high compared to the ones who used the non-gamified application. On the other hand, there were no major differences on the learnability and satisfaction indicators between both applications, which mean that participants were satisfied with both applications. Given this results, the null hypothesis is kept and the alternative hypothesis is rejected *"$H2_0$: The use of gamified elements in a lake monitoring application produces the same user experience as a with a non-gamified application"*. Each indicator and its results are explained below:

- Learnability: This indicator measures the time a participant spends to get familiar with the application. Participants were called to attend a one to one meeting for this purpose, the meeting started with an explanation about the experiment purpose and a consent agreement signing. Then, participants were given their corresponding application on a testing device. Each participant would use the application until he/she would feel that has reached an understanding on how the application works, once that feeling was reached, a voice signal was given to the researcher (e.g. *"I understand the application"*). Then, the researcher gave a tutorial about the features of the corresponding application and answered questions and comments.

  The non-gamified application users spent 166 seconds in average to understand their application during their first interaction. In comparison, the participants who used the gamified application spent 167 seconds in average. Similarly, the analysis of the dataset of this indicator shows that the learnability time in the experimental group (who used the gamified application) was similar to the control group (who used the non-gamified application) (U = 144.5; p= 0.08693).

Table 3. User Experience Indicators: Results (where: n)not significant, **)statistically significant at p<0.05, *)statistically significant at p<0.01, ****)statistically significant at p<0.001).**

Indicator	Measurment	Non-gamified Jarvida	Gamified Jarvi	Difference and sig.
Effectiveness	Submission success rate	36 %	68 %	32% **
Learnability	Time to learn to use the app	166 sec	167 sec	1 sec n
Satisfaction	Average ease to use pre survey	2,9	3	0.1 n
	Average ease to use post survey	3	2,8	0.2 n
	Average usability satisfaction	4,4	4,2	0.2 n

- Effectiveness: This indicator measured the submissions success rate. In this study, the effectiveness ratio was:

$$Effectiveness(\%) = \frac{TotalSubmissions}{TimesApplicationOpen} x100\%$$

  As it can be seen in Figure 6 (Where P is a participant), the effectiveness in the non-gamified application was 36% (*total submissions=44; times the application was open=122*). While the effectiveness in the gamified application was 68% (*total submission=260; times the application was open=381*). Hence, the effectiveness was twice higher in the gamified application compared to the non-gamified one. Furthermore, the analysis show that the submission effectiveness in the experimental group (who used the gamified application) was statistically significantly higher than the control group (who used the non-gamified application) (U=111; p=0.009844; at p<0.01).

  Participants were asked in the post survey to detail the major issues they experienced while using their corresponding application. The major reported issue was the reliability, in particular, application crashes and slow map loading. This issues can be observed in the previous calculations from the times the applications were open. This issue is further discussed in the next section.

- Satisfaction: This indicator was measured by the rate that participants gave - in a five step Likert scale - to a list of statements in the pre and post surveys (from strongly disagree to strongly agree). These statements were based on standardized questionnaires from [3, 35, 62, 61].

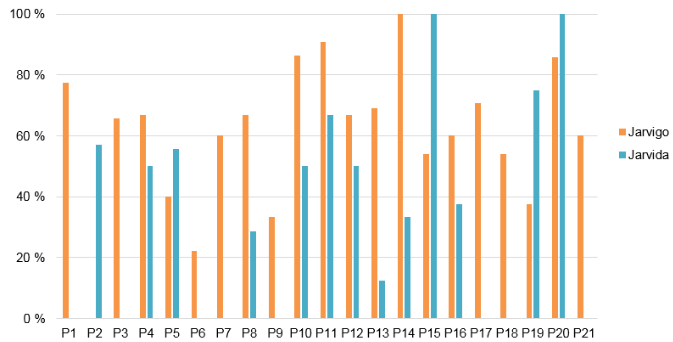

Figure 6. Comparison of Effectiveness Rates among Participants.

In the pre survey statements about ease to use from [3] were included. As it can be seen in Table 4, participants of both groups perceived their applications equally usable (as no statistically significant difference was found during the analysis).

Table 4. Mann-Whitney U test of pre survey ease to use statements (where: n)not significant, **)statistically significant at p<0.05, *)statistically significant at p<0.01, ****)statistically significant at p<0.001).**

Statements	U	p-value	Significance
I think that I would like to use this system frequently	183	0.6394	n
I found the system unnecessarily complex	186	0.6786	n
I thought the system was easy to use	204	0.9024	n
I would imagine that most people would learn to use this system very quickly	247	0.1492	n
I found the system very hard to use	203	0.9210	n
I needed to learn a lot of things before I could get going with this system	171	0.3582	n

In the post survey, the same statements about ease to use from [3] were included and a statement about usability satisfaction [35] was added. Table 5 presents the obtained results. Alike the pre survey (Table 4), both groups perceived their applications equally usable (as no statistically significant difference was found during the analysis). This is also the case for the overall satisfaction (U=158; p=0.4889).

Gamification Findings

Below we present the gamification related results from the study post survey:

- Gamification Mechanisms: Participants who used the gamified application were asked to rank statements (from 1= strongly disagree to 5= strongly agree, in a five Likert scale) about their experiences with each gamified mechanism in the post survey. The result show that the statements were ranked in the following order:

  1. Seeing my name in the leaderboard motivated me to submit more observations (3.4)
  2. I followed my progress on the activity tab (3.2)
  3. I learned about global warming with the storyboard (2.9)
  4. Seeing my points reduced motivated me to submit new observations (2.9)
  5. I achieved my challenge of submitting 20 observations in 20 days (2.4)

Table 5. Mann-Whitney U test of post survey ease to use and usability satisfaction statements (where: n)not significant, **)statistically significant at p<0.05, *)statistically significant at p<0.01, ****)statistically significant at p<0.001).**

Statements	U	p-value	Significance
I think that I would like to use this system frequently	132.5	0.142	n
I found the system unnecessarily complex	181	0.987	n
I thought the system was easy to use	144.5	0.2484	n
I think that I would need the support of a technical person to be able to use this system	159	0.2597	n
I would imagine that most people would learn to use this system very quickly	157	0.4533	n
I found the system very clumsy or difficult to use	197	0.5877	n
I needed to learn a lot of things before I could get going with this system	140	0.1464	n
I find it easy to get the system to do what I want it to do	166	0.6701	n
Overall, I am satisfied with how easy it was to use the system	158	0.4889	n

The qualitative data shows that participants paid particular attention to features such as points, leaderboard and the story. We found qualitative evidence that some participants tracked their points and reported issues they considered relevant such as: *"didn't limit observations or daily point"*(P18) or *"I didn't see that any points would have been taken from me on those days that I did submit a pic"*(P1). Also, the leaderboard appeared to be a popular feature, during the study the researchers observed that some participants noticed the presence of some of their friends in the leaderboard. This triggered a healthy social competition. A participant who was involved in this sort competition pointed out that *"it was fun and desire to submit observations incentivized me to walk more, So I would say that it is useful not only for lakes, but for people as well"*(P35). Finally, the story mechanism seems to be an effective mean to raise awareness. Jarvigo participants read the task context from the story, our qualitative analysis of their post survey comments show that they considered lakes monitoring an important issue that needs monitoring (*"A great way to study such an important issue"*(P1), *"I think that measuring ice thickness would be useful for monitoring"*(P35), *"It was fun and a good experience to provide data for such cause"*(P20)). Also, participants were critic about the quality of their observations for monitoring (*"I noticed I took many pictures of interesting rather than representative ice conditions, eg* *small area with no ice when the whole lake was otherwise frozen"*(P24)).

- Enjoyment: In the post survey, statements about enjoyment from [62] were included. Table 6 presents the obtained results. Both groups perceived their applications equal in terms of: being a good idea, interesting, liking to use the applications, enjoyable and pleasant. However, the analysis show that the experimental group (who used the gamified application) had a slight higher perception of fun (U=197; p=0.09659; at $p<0.1$) than the control group (who used the non-gamified application).

  This small difference in perception also arose in the qualitative analysis. Where, Jarvigo participants reported that they found this application interesting, effective, fun and likeable (*"It was very interesting to participate in to this project"*(P16), *"effective way to get live data from different location"*(P20),*"Otherwise it was fun and desire to submit observations incentivized me to walk more"*(P35), *"Generally I like the idea and the app"*(P35)). In contrast the Jarvida participants, found their application only interesting and relevant (*"Good idea and an important subject to study"*(P7), *"Good quest and raising awareness"* (P11), *"useful for understanding the climate change"*(P9), *"I think the idea of using the application for the lake monitoring is interesting and could make some help. And the society in general would be happy to assist"*(P23)). Also, in terms of motivation we noticed a inner motivated participant in Jarvigo who highlighted an interest in participating in future environmental sensing studies (*"Hopefully this will continue and I would participate also in the future"*(P1)). On the other hand, a Jarvida participant highlighted a lack of motivation (*"I had some lack of motivation in the sense that I didn't feel how pictures from my phone could help in lake condition monitoring"*(P23)). This puts in evidence a fundamental challenge for participatory sensing, inner human motivation. The inner motivation or lack of it has a great role onto the behavior of participants. A participant who already has an inner motivation will see it increased by the use of this mechanisms. On the other hand a participant who lacks of it can experience an opposite effect.

Table 6. Mann-Whitney U test of post survey enjoyment statements (where: n)not significant, **)statistically significant at $p<0.05$, *)statistically significant at $p<0.01$, ****)statistically significant at $p<0.001$).**

Statements	U	p-value	Significance
Using the mobile software for measurement is a good idea	166.5	0.6648	n
The program makes measuring tasks more interesting	197	0.6027	n
Working with the program is fun	233.5	0.09659	n
I like using the program to measure lakes	189	0.7904	n
I found using the system to be enjoyable	186	0.8642	n
The actual process of using the system is pleasant	171.5	0.8031	n

- Playfulness: In the post survey, statements about playfulness from [61] were included. Participants were asked to characterize themselves when they use their corresponding application (*" How would you characterize yourself when you used the system?"*). The results show (Fig 7) that the participants who used the non-gamified application would characterize themselves mainly as flexible, spontaneous and creative. On the other hand, the participants who used the gamified application would characterize themselves mainly as spontaneous, flexible and playful.

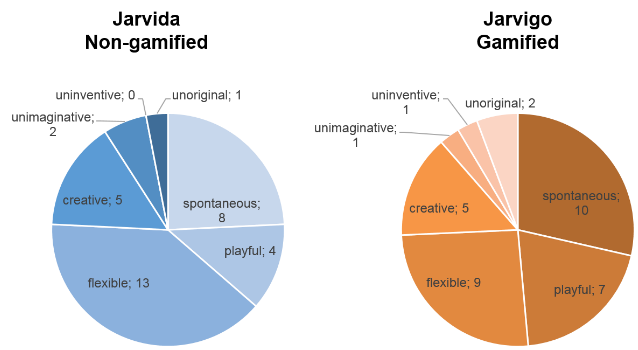

Figure 7. Application Playfulness Perceived by Participants.

Summary and Reflection

In summary, through our study we find that the gamified features of the app increased participants' submissions without affecting the perceived usability of the application.

Perception of user experience vs. actual user behavior

One of the most interesting results of this study is that *perceived* user experience and engagement did not vary between the test groups, however the test shows that the *actual* engagement (in terms of participants' submission) did vary. Self-reporting survey are a popular in research and several engagement scales have previously been successfully validated [65, 55]. However, in our study, the actual logging data tells a different story to the results collected from our self-reporting survey - this is in line with Moller et al. findings [41].

Gamification literature suggests that effective gamification involves leveraging on the game elements to foster users' three innate needs for intrinsic motivation[11] [52], originally adapted from Deci and Ryan's self-determination theory (SDT) [9]. These principles were used to foster internal motivation in the application in regard to relatedness, competence, and autonomy.

Observed impact of gamification onto engagement

Gamification depends on specific mixture and preparation of a system, which cannot be deconstructed by pieces and thus measured individually. Gamification is about *"experiences, not elements"* [10]. A game-like system has to be fun and there is a limit to deconstruction until the individual elements stop being engaging [10, 34]. Prior work in the field of participatory sensing and HCI [39, 46] have studied single game features such as the leaderboard, using also an experimental approach. The findings in this study bring insights about the

[11] Intrinsic motivation in gamification literature; autonomous motivation in self-determination theory literature

effect of gamification as a bundle of features onto human engagement. This reflects that there is no plug and play solution to engage humans into environmental sensing. Hence, gamification design should move from stimulus-effect determinism to providing fun, engaging and playful experiences [10] .

Design Reflections

Our study provides new insights into the use of gamification to enhance human engagement and user experience in participatory sensing systems for environmental monitoring. Based on our findings we suggest the following design considerations for future PS developments:

- **Support personalized notification triggers**: While some participants appreciate to not be hassled with notifications, others need notifications to remind them to submit observations *"The app could send reminds for us to use it more often"*(P2), *"Sometimes you need to have a reminder for submitting an observation , because it is easy to forget!"* (P5). The amount of notifications a participant can consider appropriate may change from person to person. Thus, PS should embedded mechanisms such as sliders to allow participants to adjust how often they wish to receive reminders.

- **Support customizable challenges to avoid negative feedback (e.g. discouragement) triggered from the lack of achievement**: Competition tends to encourage those on top of the leaderboard but, it can demotivate those who are not among the top [39]. A participant who ranked among the top in the jarvigo said that *"it was fun and desire to submit observations incentivized me to walk more"* (P35). On the other hand, there were participants whose lifestyle limited the amount of time they could spent using the application, they reported this limitation as a major issue *"I wasn't visiting the lake so often."* (P2) *"Perhaps the major issue was trying to use Jarvi more often, especially when walking near Lakes. Unfortunately, I didn't spent much time near the Lake due to busy schedule"*(P38). Mechanisms that allow the customization of the challenges (e.g. choose a challenge) and the leaderboards (e.g. choose with whom to compete or weekly resets) with the lifestyles of the participants could result into effective mechanisms for motivation.

- **Support social interaction between users**: A number of participants were motivated by competing with other participants they knew beforehand. This triggered social interactions in person between the participants. Applications such as Pokemon GO provide opportunities for their players to meet and tackle challenges together (e.g. raid battles). The sense of community is important in PS and supporting social interaction beyond likes is a promising path that requires further research.

- **Allow users to explore submitted data**: A number of participants were interested in seeing the photos recorded by other participants *"Would have been nice to see the pictures of other people what they submitted."* (P3), *"I Would have liked to get access to my own photos - and others' as well."*(P19). This supports the previous design consideration related to social interaction. Participants do their bit but also want to be part of a community and see what others are doing, applications such as Instagram have designed simple mechanisms to have such interaction. Hence, opening the submitted data to the participants could strengthen the sense of purpose by allowing participants to see the effect and reach of their submissions.

- **Enhance indoor experiences**: Going out to nature is part of the "fun" of contributing with an environmental PS initiative *"I like going to nature"*(P3) . However, ways to contribute indoors should be enhanced as well, so that participants can contribute even if they cannot go outdoors during a certain period of time (e.g. weather conditions *"It was a bit uncomfortable to use the app in cold conditions"* (P24)). This would enhance the feelings of competence and achievement. Applications such as Galaxy Zoo are built around indoor experiences, where participants perform classification tasks at their computers.

- **Support interactive feedback**: Several participants suggested new features and improvements to the current system via the surveys; *Maybe instead of google maps it would more reliable and robust to just have a static map like picture with some coordinates system on it"* (P28), *"suggestion is to provide some lighter version of the application, especially for slow connection internet"*(P32), *"In my opinion, the steps of adding new spot and then adding ice information to that spot could integrated into one step. Also, there could be some note that you can use the same spot for multiple times to record observations."*(P33). This comments unveil an opportunity to involve the participants as a co-creators. This behavior needs to be enhanced via design mechanisms that encourage feedback and co-creation from participants.

LIMITATIONS AND FUTURE WORK

Limitations

The first limitation of this study is its short duration which was not enough to explore how participants' behavior change over time. However, this was out of scope of this study.

Although some insight about the individual effect of each gamification feature onto engagement was illustrated using the qualitative data collected via surveys. This analysis is limited by the current study data (which is mainly quantitative) and could be improved by more usage data statistics in future studies.

Another limitation is the unfamiliarity of few participants with Android devices, as the developed sensing applications were only available for iOS and Android. As a result, six participants received devices with their respective sensing application installed for the time of the study. This might have had an effect on the learnability measure, because the participants had to learn to use a new device on top of learning how to use the application.

Future Work

Participatory Sensing faces several challenges including privacy and security concerns, data quality and standardization. Yet, participation is fundamental to capture contextual local knowledge about patterns that often are ignored in bigger scales. Some studies have already looked into what motivates people to get involved in participatory sensing projects [19, 15]. However, it still remains unanswered how could the effect of ICT on engagement be scaled up to larger time spans, and how PS could be used to engage citizens as designers and innovators. Following this study, we will design an action research intervention to explore the participants' engagement over a longer period of time. This subsequent study will explore whether co-creation as a design approach enhances both the feeling and perception of engagement, and longer-term effects [51].

CONCLUSIONS

In this work, we present the results from an experimental user study that explored the impact of gamification on engagement and user experience. We designed, deployed and evaluated two environmental sensing applications (one gamified and one non-gamified) via a 20 days experiment with volunteers. We found that gamification affected the participants' engagement in a positive way (producing more submissions), without improving nor compromising their user experience. This led us to think that in order to produce human engagement, altering interfaces is not enough. This supports the review results of Nacke et al. [44] that adding simple visual manifestation of gamification elements or deterministic mechanics to the interface is not enough without considering other aspects of engagement. Deterding et al. propose [10] that gamified motivation design should move from stimulus-effect determinism to providing fun, engaging and playful experiences. Our participants mentioned "proving data for a good cause", "I like going out to nature" and "it is useful not only for lakes, but for people as well" as motivating factors. This leads us to conclude that the gamification design for environmental sensing had a positive effect on participants' engagement.

Even when the underlying technology is still evolving, participatory sensing has already shown its great potential, not only as a tool for citizens' collecting data but also as a vehicle for engaging a large public community in solving social and environmental challenges. These systems have the potential to close the gaps among researchers, environmental experts, decision-makers, and the people, while collecting data and building a whole new level of services (from the people, for the people). However, the success of participatory sensing relies heavily on continuous citizen participation and the computational capacity to extract patterns from the data being collected.

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