

Motivations, learning and creativity in online citizen science

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Abstract

Online citizen science projects have demonstrated their usefulness for research, however little is known about the potential benefits for volunteers. We conducted 39 interviews (28 volunteers, 11 researchers) to gain a greater understanding of volunteers' motivations, learning and creativity (MLC). In our MLC model we explain that participating and progressing in a project community provides volunteers with many indirect opportunities for learning and creativity. The more aspects that volunteers are involved in, the more likely they are to sustain their participation in the project. These results have implications for the design and management of online citizen science projects. It is important to provide users with tools to communicate in order to supporting social learning, community building and sharing.

Keywords

Citizen science; Informal learning; Public engagement with science and technology

Introduction & background

Citizen science is a research practice where members of the public (non-professional scientists) collaborate with professional scientists to conduct scientific research [Wiggins and Crowston, 2011]. Citizen science projects that utilize technology — online citizen science projects, also known as “citizen cyberscience” — enable researchers to tackle research questions that otherwise could not be addressed. However little is known about the potential benefits of citizen cyberscience for volunteers. Why do volunteers take part and what do volunteers learn through their participation? In this paper we aim to produce a new understanding of learning behaviours and creative outputs, providing valuable insights into the experience of citizen cyberscience volunteers. We start by presenting a review of the literature, in which we give an overview of different kinds of cyberscience and review what is currently known about volunteers' motivations, learning and creativity. Then we present the objectives, methodology and findings of our interview study.

Citizen cyberscience

The growth of the Internet and mobile technology has substantially increased the profile of citizen science, by increasing project visibility, functionality, and

accessibility [Bonney et al., 2014]. Haklay [2013] refers to projects that utilize technology projects as *citizen cyberscience* and identifies three categories: volunteer computing, volunteer thinking, and participatory sensing.

In *volunteer computing*, participants install software on their personal computers to enable projects to utilize their unused processing capacity. The Berkeley Open Infrastructure for Network Computing system (*BOINC*)¹ allows data to be processed for a range of projects, including physics,² climate change,³ and biology.⁴ Such projects are thought to require little effort from volunteers, because all participants need to do is install the required software.

In *volunteer thinking*, participants are engaged at a more active and cognitive level. Volunteers typically visit a website where they are presented with data and they are trained to analyse the data according to a certain research protocol. Examples include classifying galaxies,⁵ classifying bat calls,⁶ transcribing weather information,⁷ mapping neurons,⁸ and folding proteins.⁹ Besides science research, volunteer thinking projects can also be found within humanities research. Examples include annotating war diaries from the First World War,¹⁰ transcribing ancient Egyptian papyri,¹¹ and transcribing unstudied manuscripts written by the philosopher Jeremy Bentham.¹²

The third kind of citizen cyberscience activity is *participatory sensing*. Participants typically download a mobile phone app which allows them to collect data by utilizing sensors that are already integrated in their mobile phone. These sensors include different transceivers (mobile network, WiFi, Bluetooth), FM and GPS receivers, camera, accelerometer, digital compass and microphone. For example, volunteers can collect data about local animal species^{13, 14} plant species,¹⁵ air quality,¹⁶ and noise levels^{17, 18}. Sometimes volunteers are also asked to submit behavioural information, such as rating how happy they feel,¹⁹ or tweeting errors they had experienced that day.²⁰

¹BOINC. <https://boinc.berkeley.edu/>.

²LHC@home. <http://lhcatome.web.cern.ch/>.

³Climateprediction.net. <http://www.climateprediction.net/>.

⁴Rosetta@home. <http://boinc.bakerlab.org/>.

⁵Galaxy Zoo. <http://www.galaxyzoo.org/>.

⁶Bat Detective. <http://www.batdetective.org/>.

⁷Old Weather. <http://www.oldweather.org/>.

⁸Eyewire. <https://eyewire.org/signup>.

⁹Foldit. <https://fold.it/portal/>.

¹⁰Operation War Diary. <http://www.operationwardiary.org/>.

¹¹Ancient Lives. <http://www.ancientlives.org/>.

¹²Transcribe Bentham. <http://blogs.ucl.ac.uk/transcribe-bentham/>.

¹³Project Noah. <http://www.projectnoah.org/>.

¹⁴Kent Reptile and Amphibian Group (KRAG). <http://www.kentarg.org/>.

¹⁵Floracaching. <http://biotracker.byu.edu/>.

¹⁶Mapping for Change. <http://mappingforchange.org.uk/>.

¹⁷Everyaware. <http://www.everyaware.eu/the-everyaware-project/>.

¹⁸Wide Noise. <http://cs.everyaware.eu/event/widenoise>.

¹⁹Mappiness. <http://www.mappiness.org.uk/>.

²⁰Error diary. <http://www.errordiary.org/>.

Motivations

Researchers have investigated volunteers' motivations for participating in a variety of citizen cyberscience (and humanities) projects, including:

- Galaxy Zoo [Raddick et al., 2010; Raddick et al., 2013],
- Transcribe Bentham [Causer and Wallace, 2012],
- Happy Moths [Crowston and Prestopnik, 2013],
- SETI@home [Nov, Arazy and Anderson, 2010; Nov, Arazy and Anderson, 2011],
- Stardust@home [Nov, Arazy and Anderson, 2011],
- Eyewire [Iacovides et al., 2013],
- Foldit [Iacovides et al., 2013; Curtis, 2015],
- Folding@home [Curtis, 2015],
- Planet Hunters [Curtis, 2015],
- Old Weather [Eveleigh et al., 2014],
- Errordiary [Jennett et al., 2014], and
- Floracaching [Bowser et al., 2013],

Researchers have also investigated motivations across ecological projects [Rotman et al., 2012; Rotman et al., 2014] and Zooniverse projects [Reed et al., 2013].

Together these research studies suggest that volunteers are motivated by a combination of many different factors, including:

- Interest in the research topic [Raddick et al., 2010; Causer and Wallace, 2012; Crowston and Prestopnik, 2013; Iacovides et al., 2013; Curtis, 2015; Eveleigh et al., 2014; Jennett et al., 2014; Reed et al., 2013]
- Learning new information [Raddick et al., 2010; Crowston and Prestopnik, 2013; Nov, Arazy and Anderson, 2010; Reed et al., 2013]
- Contributing to original research [Raddick et al., 2010; Raddick et al., 2013; Nov, Arazy and Anderson, 2010; Curtis, 2015; Jennett et al., 2014; Reed et al., 2013]
- Enjoying the research task [Raddick et al., 2010; Crowston and Prestopnik, 2013; Nov, Arazy and Anderson, 2010; Nov, Arazy and Anderson, 2011; Curtis, 2015; Eveleigh et al., 2014; Jennett et al., 2014; Reed et al., 2013]
- Sharing the same goals and values as the project [Nov, Arazy and Anderson, 2010; Nov, Arazy and Anderson, 2011; Rotman et al., 2014]
- Helping others and feeling part of a team [Raddick et al., 2010; Nov, Arazy and Anderson, 2010; Nov, Arazy and Anderson, 2011; Iacovides et al., 2013; Curtis, 2015; Jennett et al., 2014; Bowser et al., 2013; Rotman et al., 2014; Reed et al., 2013]

- Recognition of contribution and feedback on contribution [Causser and Wallace, 2012; Iacovides et al., 2013; Curtis, 2015; Eveleigh et al., 2014; Bowser et al., 2013; Rotman et al., 2012]

Another important finding is that motivations can change over time. Citizen cyberscience projects typically have a skewed pattern of participation, where a large proportion of volunteers contribute in small quantities [Eveleigh et al., 2013]. Rotman et al. [2012] found that volunteers' initial interests in environmental projects stemmed from factors such as personal curiosity and previous engagement in citizen science; while ongoing participation was affected by factors such as recognition, attribution, feedback, community involvement and advocacy. Iacovides et al. [2014] found similar results in their study with Foldit and Eyewire volunteers: motives for joining a project included having an interest in science and being pro-citizen science; while sustained engagement was influenced by factors such as recognition, gaming elements, and team-play.

However a limitation of past research is that studies typically focus on one citizen cyberscience project (e.g. Galaxy Zoo) or one type of citizen cyberscience project (e.g. volunteer thinking). Therefore one of our goals was to create a model that can be applicable across citizen cyberscience projects.

Recently Curtis [2015] conducted surveys and interviews with volunteers of Foldit (volunteer thinking), Folding@home (volunteer computing) and Planet Hunters (volunteer thinking). In her thesis she explored how motivation, interaction and contribution were inter-connected. She found that the greater the complexity of the project, the greater the likelihood that participants would co-operate and collaborate with others. A high level of interaction between participants was a powerful motivator and could help to sustain participation. Also, being able to contribute to a project in number of different ways (e.g. as a team leader, or moderator) can motivate an individual to sustain participation, particularly if this contribution is felt to be of importance and is valued. Curtis' thesis [2015] is very relevant to our research goals and in our work we also aim to explore the relationships between motivation, participation and interactions with others.

Learning

It is commonly thought that citizen science projects result in participants' learning about the research topic and developing scientific literacy, through observation and experiencing the process of scientific investigation. This learning could occur both informally (incidental learning) and formally (whenever scientists provide formal teaching to train volunteers). Yet there is limited research investigating how participation in Citizen Science projects affects learning. As Crall et al. [2013] states, *"The growth in citizen science programs over the past two decades suggests that we need to evaluate their effectiveness in meeting educational goals."*

Previous studies that have investigated learning have focused on effects of participation on scientific literacy [Crall et al., 2013; Bonney et al., 2009; Cronje et al., 2011], content-knowledge [Jordan et al., 2011; Crall et al., 2013] and changes in everyday behavior [Jordan et al., 2011]. These studies are convergent in reporting:

- Some on topic knowledge gains [Crall et al., 2013; Jordan et al., 2011], however progress may not be significant as volunteers may have a good previous content knowledge;
- Limited improvement of scientific process skills [Ballard and Belsky, 2010] and science literacy [Cronje et al., 2011; Jordan et al., 2011].

However these studies deal with conservation projects (traditional citizen science) as opposed to citizen cyberscience.

Recently Price and Lee [2013] investigated how volunteers' attitudes towards science changed after six months of participation in the citizen cyberscience project Citizen Sky.²¹ Their results revealed that improvements in scientific literacy were related to participation in the social components of the program but not to the amount of data contributed. This highlights the important role of wider communities in learning, a finding that has also been highlighted in the context of informal learning through involvement in digital gaming practices [Iacovides et al., 2014]. But again it is unknown whether these findings are applicable to other citizen cyberscience projects. Therefore our second goal was to investigate learning across citizen cyberscience projects.

Creativity

Creative outcomes are commonly thought to occur as a result of volunteers participating in citizen cyberscience. There have been a few cases where citizen cyberscience research has led to important scientific discoveries, Foldit being the most famous. In 2011, it was reported that Foldit players managed to uncover a protein folding structure underlying the HIV enzyme within 3 weeks, a puzzle that had stumped professional researchers for decades.²² Following on from this discovery, researchers have studied Foldit players to try to understand how they codify their strategies, share them and improve them [Khatib et al., 2011; Cooper et al., 2011].

Serendipitous discoveries have also been made due to the self-organised efforts of volunteers. In 2008 a group of Galaxy Zoo volunteers discovered "green peas", galaxies that were originally overlooked by the science team because they thought the green appearance was merely an artefact of the imaging apparatus. Having a forum to comment and discuss ideas was crucial in enabling this discovery to take place [Tinati et al., 2015].

However this research is limited because it only focuses on a single citizen cyberscience project. Further, there could be other kinds of personal creations from volunteers, less ground-breaking, but also valuable for a project's success. Psychologists refer to this as *everyday creativity* [Boden, 1990; Candy and Edmonds, 1999]. Therefore our third goal was to explore different kinds of personal creations across citizen cyberscience projects.

²¹Citizen Sky. <http://www.aavso.org/citizensky>.

²²Foldit gamers solve riddle of HIV enzyme within 3 weeks. Posted online on Scientific American, September 20, 2011. <http://www.scientificamerican.com/article/foldit-gamers-solve-riddle/>.

Aim

Overall the aim of our interview study was to gain a better understanding of volunteers' experiences in citizen cyberscience. In particular we wanted to understand:

1. What factors motivate volunteers to join a citizen cyberscience project? What factors sustain their engagement? What are the barriers for engagement?
2. How do volunteers learn in citizen cyberscience projects and what do they learn?
3. What are the different kinds of personal creations in citizen cyberscience? Why do volunteers create them?
4. How are these themes related?

Method

The selection of potential interviewees was based on *purposeful sampling* and *opportunity sampling*. We wanted our sample to consist of projects that represented different kinds of citizen cyberscience activities. To aid recruitment, we also wanted to take advantage of projects that we had existing ties with, e.g. projects based at UCL and/or projects where we already had contact details for the project leaders. We selected 7 projects to represent the range of citizen cyberscience categories: volunteer computing (1), volunteer thinking (4) and participatory sensing (2). Emails were sent to project leaders, where we explained the purpose of our research and asked whether one (or more) of their research team would be willing to be interviewed. We also asked project leaders to post an advert on their project forum and mailing list on our behalf to encourage their volunteers to take part in our interview study. This resulted in 39 interviews: 28 with volunteers and 11 with professional researchers. See Table 1 for more information.

Table 1. Demographics of interview participants.

Project name	Project category	Number of interviews	Roles of interviewees	Other demographic information
BOINC https://boinc.berkeley.edu/	Computing	8	7 volunteers 1 researcher	7 males
Old Weather http://www.oldweather.org/	Thinking	18	17 volunteers 1 researcher	10 females, 7 males
Eyewire https://eyewire.org/signup	Thinking	6	5 volunteers 1 researcher	3 females, 2 males
Transcribe Bentham http://blogs.ucl.ac.uk/transcribe-bentham/	Thinking	3	2 volunteers 1 researcher	1 female, 2 males
Bat Detective http://www.batdetective.org/	Thinking	2	1 volunteer 4 researchers (group interview)	3 females, 2 males
EveryAware https://eyewire.org/signup	Sensing	1	1 researcher	1 male
KRAG http://www.kentarg.org/	Sensing	1	1 researcher	1 female

As can be seen in Table 1, the majority of interviews were conducted in three projects: *BOINC*, volunteer computing; *Old Weather*, a volunteer thinking project where participants transcribe weather data and historical information from the handwritten logbooks of 19th century naval ships; and *Eyewire*, a volunteer thinking project with a gaming dimension where participants color puzzles and reconstruct neurons of the retina of a rat. For *Old Weather*, we interviewed 10 volunteers that were still actively involved, and also 7 volunteers that were no longer active in the project but still on the project mailing list. This allowed us to gain an insight into the reasons why volunteers may choose to no longer participate.

Other projects included: *Transcribe Bentham*, a volunteer thinking project where participants transcribe the unpublished manuscripts of the London philosopher Jeremy Bentham (1748–1832); *Bat Detective*, a volunteer thinking project where participants listen to audio recordings and classify bat calls; *EveryAware*, a project with several case studies involving volunteer sensing, where participants use mobile apps to investigate sound pollution and air quality in their local area; and *KRAG*, a volunteer sensing project where participants record sightings of *herpetofauna* (reptiles and amphibians), promoting conservation of herpetofauna in Kent.

All interviews were semi-structured, based on a general list of pre-defined concepts and probes. The majority of interviews took place virtually over Skype (28 volunteers, 3 researchers). Four interviews took place in person at UCL (7 researchers, where 3 were interviewed individually and 4 were interviewed in a group). Interviews were audio recorded and varied in length, from 30 minutes to 1 hour.

Interview transcripts were analysed using *thematic analysis* [Braun and Clarke, 2006]. This involves coding relevant sections of the transcript in a consistent way, and subsequently grouping those codes into themes. *Themes* help to explain what the data means and relate the data to research questions. Four researchers coded the data separately to uncover themes for motivation, learning and creativity. During a two-day workshop, the researchers discussed and compared their analyses, building a model of volunteers' motivations, learning and creativity.

Note that we have presented parts of our interview dataset at workshops and conferences [Jennett et al., 2013; Kloetzer et al., 2013; Eveleigh et al., 2013; Eveleigh et al., 2014]. However this is the first time we have presented our analysis of the full dataset, with the goal of building a model of motivation, learning and creativity.

Results

We will describe our themes for volunteers' motivations, learning and creativity. Then we will present our model outlining how these themes relate to each other.

Motivations

In Figure 1 we present our thematic map for volunteers' motivations.

Our thematic analysis revealed that volunteers are initially motivated to participate in a citizen cyberscience project for three main reasons: curiosity, interest in science and desire to contribute to research. Volunteers described how they had some free

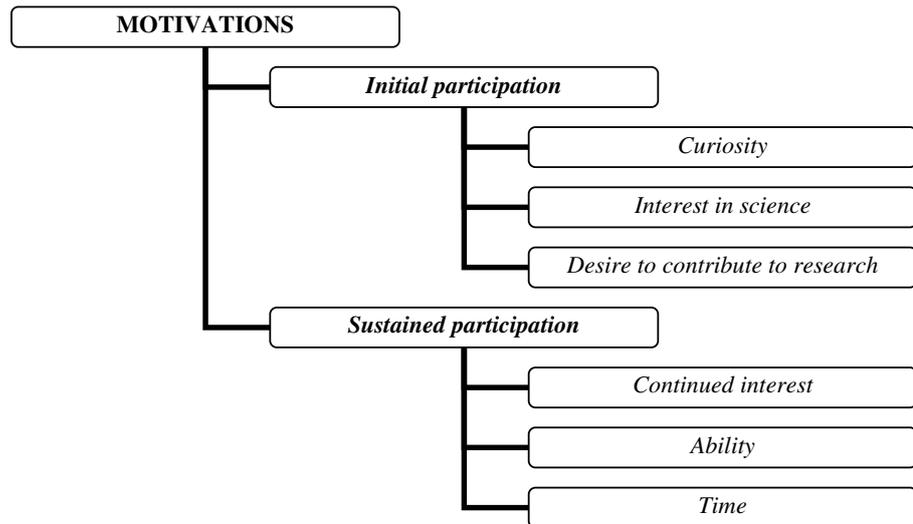


Figure 1. Thematic map of volunteers' motivations.

time to browse the Internet, they heard about the project, thought it sounded interesting so they tried it out. Volunteers found out about citizen cyberscience projects through science articles, news stories and citizen science portals (e.g. Zooniverse):

"I thought it would be mildly diverting thing to do. I read about in on the BBC website, clicked on the story, found it interesting, so decided to give it a go." Old Weather volunteer

"I was with Zooniverse, I found Bat Detectives, I found it very interesting and I am learning a lot about bats now... let's say I have a curious mind I like to... time is not very important for me." Bat Detective volunteer

"There was an article on a science webpage, 17 games doing science. Eyewire described as one of the most robust and developed." Eyewire volunteer

After their initial experience of participating in the project, three factors impact volunteers' motivations to continue participating: continued interest, ability and time. Volunteers felt motivated to participate more than once if they felt like they had aptitude for the task and they enjoyed participating in the task and/or the activities surrounding the project (forums, chat). Volunteers described how it was important that they felt like they were making a useful contribution to research and they were having a good time while they were doing it:

"It's a fascinating hobby for me. But I think there must be a huge amount of scope in the information recorded in the historical documents. Also it's great that these logs are being made more accessible by digitising them, as not everyone can get to the national archives to read them in person." Old Weather volunteer

"It is a very addictive game. It is... I like the colours and I like contributing to science as I participate in it, it is a lot of fun. I like the community, so there are lots of things going on at all times, and there is this chat function, we can communicate with one another and I like to participate in those conversations." Eyewire volunteer

"That's why the mini-teams are useful! It brings competition. Team spirit and internal competition. If not, people get bored." BOINC volunteer

Some volunteers will try out a project once and then never take part again, or their participation may dip over time. Barriers for sustained engagement included finding the task difficult and/or boring:

“I really liked the concept, but I had trouble deciphering the handwriting. So I was afraid I was getting things wrong and I... if there were ones that I could be sure I was doing right then I would love to keep doing it, but I was afraid of screwing it up.” Old Weather volunteer

“I think the people that get involved for a long time, like myself, just get interested and find it so fascinating that you can’t quit. I think the people that get involved for a short time, they may get bored, they may find it’s too much work, they may worry about the responsibility [...] And some I think might just get into it and find that it’s not what they expected. Sometimes it does kind of get boring when you’re banging through day after day and it’s the same kind of thing. They might just decide it’s not really what they were interested in and just quit.” Old Weather volunteer

Continuing to have the time to participate is also an important factor. The most dedicated volunteers appear to get into a rhythm of working, often checking the project website daily. By participating regularly they stay up to date with project news, they gain greater aptitude for the project task, and they become increasingly familiar with other volunteers. This allows them to identify with the project community and feel a sense of belonging:

“I think it works very well because you’ll see on the forum for Old Weather there’s a group of people who are very dedicated and they are... it’s a group of people who post, well it’s not just posting, but talk to each other quite frequently and they work together.” Old Weather volunteer

“Oh because I have the time! You know I’m retired and if you’re working you’re not going to have as much time. And you know, I can do it, so I do do it.” Transcribe Bentham volunteer

“It fits very well into my daily life. I play while doing homework (for breaks) and while my family watches TV. I also play a bit before I head off to classes or to do errands, so pretty much anytime I can squeeze in a few minutes of play-time, I do it.” Eyewire volunteer

However levels of participation can vary over time and it is possible for even the most dedicated volunteers to lose this rhythm. Several volunteers described how their contribution levels dipped because other things in their life (work, studying, family, hobbies) had taken priority and they no longer had the time:

“I signed up in November, but it was during finals and I didn’t have time to start right away. But once I did, I fell in love with the game, the science behind it, and the people who created and ran the game. I’ve played games online for over a decade, and finding a game that had a ‘purpose’ was very rewarding.” Eyewire volunteer

“I think other things just ended up taking over, you know time there’s only 24 hours in a day, other things ended up... it was cool for a while, but then I ended up doing enough other things in life that I didn’t feel like doing that in addition. But if I ever had a lot of time again where I was just sort you know... I might consider doing that again a little bit.” Old Weather volunteer

Learning

In Figure 2 we present out thematic map for volunteers' learning.

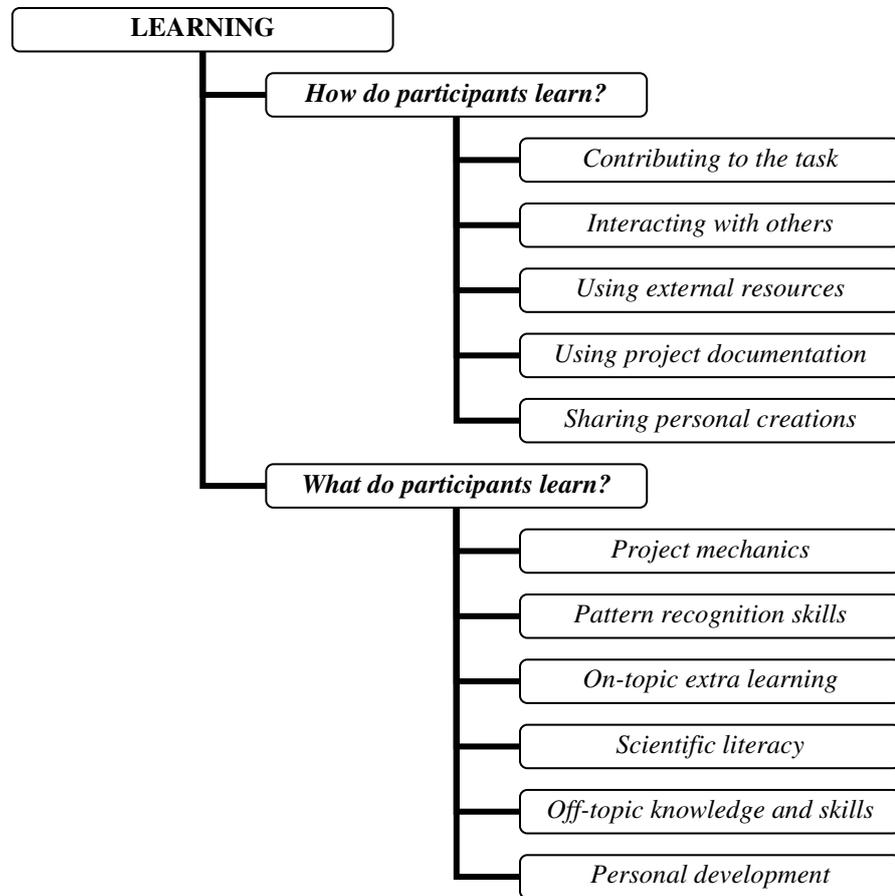


Figure 2. Thematic map of volunteers' learning.

Learning happens as a result of participating in a citizen cyberscience project, see Figure 2. With respect to “*how do participants learn?*” we distinguish between participation on a micro and macro level [Iacovides et al., 2014]. *Micro learning* results from contributing to the task, for example, what participants learn when they engage in observing species, classifying objects, solving puzzles. *Macro learning* results from using external resources, using project documentation, and sharing personal creations. Interacting with others can happen in both contexts (micro and macro) and seems to boost learning.

Regarding “*what do participants learn?*” our thematic analysis revealed six types of learning outcomes. Participants firstly learn *project mechanics*, including the commands of the interface, the rules and concepts of the game. For example in *Eyewire*, there are videos presenting the project, online tutorials and training sequences. These tools help volunteers learn the interface, the buttons to click and commands to activate to perform the task. Volunteers described learning about the rules of the game, especially the credit system (how points are calculated), how this credit system relates to their performance, and how they can use these results as a feedback tool to improve themselves. Volunteers also described learning specific concepts instantiated in the game. For example, they described learning what “*trail*

blazing” means, a term used in *Eyewire* to refer to the first player exploring a new cube. By requesting help in trying to solve technical problems, volunteers might also find themselves in touch with the project’s community for the first time. Learning happens at this level by the transformation of novices, who frequently ask questions, to more expert volunteers, able to answer these questions.

A subset of citizen cyberscience projects (volunteer thinking) ask volunteers to analyse data by identifying recurring patterns defined by the research team. In these kinds of projects, participants develop *pattern recognition skills*. By looking repeatedly at the same kind of data, with clear analysis instructions, volunteers get a sense of what is meaningful in these data. Learning to “*guess correctly*” is part of the process in that case, and knowledge of specific terms as well as expectations on what should normally follow, help volunteers to do their work confidently:

“And as time goes on, I ended up enjoying the ones with challenging handwriting. You get an eye for the pattern of squiggles. I couldn’t have started with difficult ones, but I can do them now, and I enjoy them most.” Old Weather volunteer

As well as gaining content knowledge from participating at the micro level (contributing to the task), content knowledge can also be acquired at the macro level, through additional involvement of the volunteer beyond the task itself. We refer to this as *on-topic extra learning*. Volunteers described how the task motivated them to find out more about different related topics, by interacting with others and consulting external resources such as the Internet or books:

“Now I’m doing a ship that has just, as of last night, has finished blockading Cuba. Eventually it’s supposed to go back up towards the North Pole. Sometimes you look at these things and say, ‘What the heck is going on?’ and then you start googling ‘What was going on in Havana in 1888’, why am I here?” Old Weather volunteer

Some volunteers have specific roles in the project community. For example, in BOINC they offer specific roles and responsibilities to distinguished members. Administrators take the responsibility of running the community at a technical level and taking fundamental decisions. Moderators take the responsibility to moderate, clean and tidy the forums, as well as to initiate discussions and support newcomers. Some volunteers update specific sections or projects, going on the Internet to find the latest information and translating them to share them with the community; while others read, summarize or translate research reports, news and papers. In all of these activities, volunteers may learn about the relevant research topic, e.g. physics, climate change, or biology. “*Being in charge*” therefore increases learning, as one performs additional work for the benefits of the whole community.

Another learning outcome is the development of *scientific literacy*. Volunteers gain a better understanding of what science does and how scientists work, which research questions they are trying to answer and how they try to answer them. Direct experience of scientific data and analyses also allow volunteers to understand that science involved the use of rigorous procedures and protocols, that science takes times, and that failures are considered normal risks and contribute to exploration. These effects can be appreciated for example, by the increased accessibility of popular scientific publications to volunteers:

“It transforms the short term vision. Experimenting with Citizen Science projects, people understand that science takes more time and may have different goals. Science is not only a financial statement at the end of the semester or year. There is a long term vision.” BOINC volunteer

“I truly opened myself a lot. Today when I come to read a scientific magazine, it is very nice to understand all the text without having to check half of the words!” Eyewire volunteer

Off-topic knowledge and skills refers to learning content knowledge or procedural skills exceeding the scope of the project. We found that volunteers may develop knowledge and skills related to the indirect requests of the task and the opportunities offered by the project. Some of these skills are specific to the characteristics of the project. For example, *Old Weather* volunteers described how they improved their handwriting reading skills, while *BOINC* volunteers described how they improved their understanding of GPUs and Virtual Machines. There are also more general skills reported across all of the citizen cyberscience projects, such as communication skills and web literacy:

“Step by step I learned how to post links and the whole HTML language, which I know quite well now, without taking courses. The other members helped me a lot. We help each other, sometimes we discover things together. We created a sandbox to practice, where we have been trying to design tabs. We have been learning the writing codes all together.” BOINC volunteer

Almost all citizen cyberscience projects are designed in English. For non-English speakers, this is an important barrier which prevents them from participating to the project. However, for some participants who speak English well enough to be able to participate, the project provides opportunities for improving their English, by reading English documents and interacting with the project community.

Volunteers develop online communication skills by learning to use the discussion tools provided by the projects. Volunteers get a chance through peer-guidance to learn the right way to ask questions, write answers, initiate and contribute discussions. For example, some volunteers described how they had never used a forum or a chat room before. Thus citizen cyberscience projects provide structured ways to get familiar with communication tools that are widely present on the Internet.

For those volunteers that are assigned administrator or moderator roles, they learn to manage a community that deals with a real-life scientific project and involves participants from different age ranges and very diverse professional backgrounds, such as students and retired people. Examples of community management activities include keeping people involved, organizing events and sometimes internal and external competition, taking decisions, operating technical platforms, creating and animating teams, managing “flaming”, organizing the yearly life of the community.

The final learning outcome is *personal development*. Volunteers described how their experience of participating in the project allowed them to increase their self-confidence, expand their personal interests, extend their social network, assume new roles in a science-based community, and inspire creative works:

“It opens up your world and your mind. It allows you to be able to get different perspectives on something you may not have understood or known about before, or even things in your everyday life, it can open up in a new way where you can see it differently. It takes you on different paths, gives you new adventures to do in your everyday life that otherwise you may not have even considered doing.” Volunteer from Eyewire

“I have been here for only two years, but there are people here I would like to meet, and I am sure we would become friends. In the forum, in the admin zone, I talk like I would talk to friends, and they do the same.” Volunteer contributing to BOINC projects

Creativity

In Figure 3 we present out thematic map for volunteers’ personal creations.

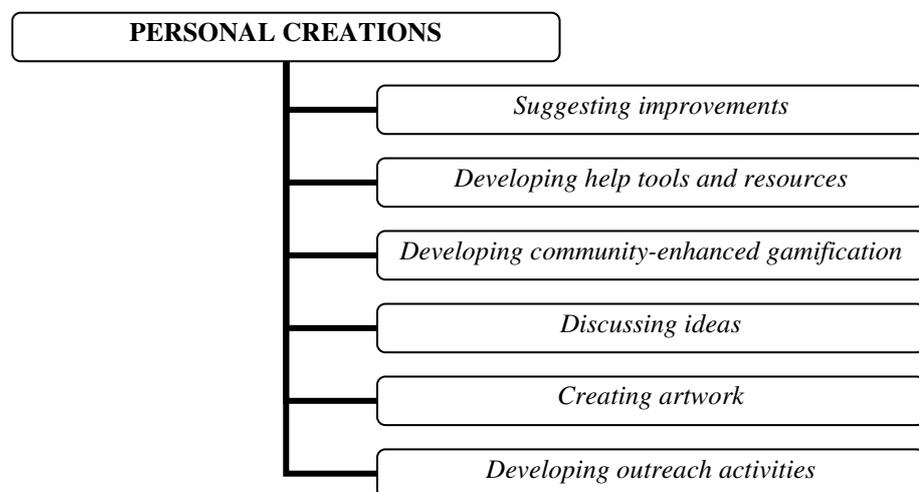


Figure 3. Thematic map of volunteers’ personal creations.

Our thematic analysis revealed many different kinds of personal creations that resulted from participation. Several volunteers described how they *suggested improvements* for the task, which they communicated by posting on the project forum or sending the researchers a private email. Researchers viewed volunteers’ feedback and suggestions as valuable for helping them to improve the task interface:

“I sent them from mails from time to time with things I believe might be bugs or things I don’t understand [...] they are really kind to me, they respond! I think they are glad that I am trying to help them.” Eyewire volunteer

“The volunteers are our experts really in updating the transcription interface. It’s been suggested by them if we could eliminate the mark-up, if we could introduce an automatic save feature [...], improvements to the image viewer [...] They’ve certainly offered a lot of input in that regard. And when we update the transcription interface and test it, they will be the key audience for doing so.” Transcribe Bentham researcher

Sometimes volunteers developed *help tools and resources* in order to make the research task easier. In Old Weather, some of the volunteers created glossaries and naval-related lists to make the task of interpreting the ships’ logs easier. In BOINC, there were examples of volunteers translating instructions in other languages. In

Eyewire, one of the volunteers described how she created a bot (a software application that runs automated tasks) to answer commonly asked questions.

There were also community outputs that were developed for the purpose of adding to the life of the community, making it more fun. We refer to these kinds of outputs as *community-enhanced gamification*. Volunteers add to the competitive elements that are already built into the projects, enabling an extra layer of competition for players to get excited about. Some BOINC volunteers created websites to display stats and graphs about the performance of different teams. Similarly in Eyewire, one volunteer created a bot to announce new cubes and to calculate statistics:

"[...] he also created a small bot, mostly for the hardcore players I would say, identifying new cubes, announcing whenever a new cube is created, as they sometimes really run out of cubes in one cell. He also processed the responses for some cool statistics. Like how many players from which countries are participating. The overall scores for every player. Total points earned on Eyewire for each day and son on..."
Eyewire volunteer

Discussing ideas with others via the forum / chat was also viewed as a way of expressing yourself creatively. Novelty and humour play a role in how creative a post is perceived to be. As one volunteer describes, it is possible that a forum thread that started off as "*just for fun*" can also end up having scientific value for the project:

"[...] found a little green galaxy and she started a thread called 'Give peas a chance' with peace spelled p-e-a-s and everyone thought it was funny and we started collecting these green blobs [...] then we asked the scientists 'well is there something special or is it just for fun?' and apparently they are a special kind of galaxy. And there are papers written about it too, about green peas, and the peas are an accepted term!" Old Weather volunteer [talking about Galaxy Zoo]

"I am sometimes impressed by conversations, by what people are discussing about. Some people who play are scientists in their own real life and they do interesting work and sometimes they share it in the forum and that's interesting to read about. I am not sure that is contributing to the game, but it is contributing to the community."
Eyewire volunteer

Participants also gave examples of volunteers creating *artwork* which they shared on the forums. For example, Old Weather has a forum thread called *Dockside Gallery*, where volunteers post paintings of the ships whose log books they are transcribing. These posts were appreciated for their aesthetic value:

"There is one person I know that has done artwork on the forums, taking the ships and doing colour formatting, outlining, and I thought 'Oh we need to get that on T-shirts!'" Old Weather volunteer

A further way that volunteers were creative was developing *outreach activities*. For example, BOINC volunteers created research presentations and tutorials to promote the project. Similarly, a researcher working with on various environmental projects described how she found outreach activities, such as presenting their work to schools, was the most creative part of her work:

“Three members created documents to present BOINC in schools and universities. They have been documenting all the critics that we face: security risks, increased computer wear-off, etc. These topics are regularly discussed in the forum, and we begin to have a lot of material to answer them.” BOINC volunteer

“I would say the creativity will come with outreach [...] we also have people in the wild life trust who get involved with us and they do a lot of delivery to schools, secondary school and primary school so a lot of the time people who do get involved have that skill set and it just happens to be for frogs and snakes.” KRAG researcher

Motivation-Learning-Creativity (MLC) model

We developed a model to explain how motivations, learning and creativity are related, which we called the MLC model. In the MLC model (see Figure 4) we propose that learning occurs as a result of participation. The more a volunteer participates in different aspects of a project (micro and macro-levels), the more they learn and the more their identity as a project volunteer deepens. Identifying as a project volunteer involves three aspects: self-confidence, feeling that they are contributing to research, and feeling that they belong to the project community.

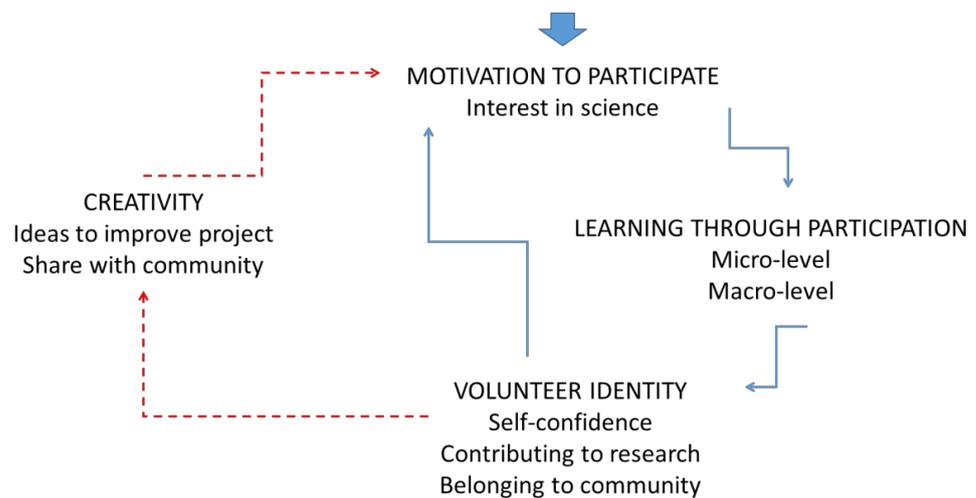


Figure 4. MLC model of motivation, learning and creativity in citizen cyberscience.

Learning in citizen cyberscience tends to be informal, unstructured and social. In relation to motivation, we see a virtuous cycle: a volunteer improves her knowledge and skills by doing the task, sharing this in a community of peers helps to increase her self-confidence, also increasing her ability to perform the task and her desire to share. The community supports the development of confidence and identity because learning includes a meta-dimension: it is about becoming and knowing one is competent in a field. This often happens through the discovery that one is now able to help others. Here we have a virtuous circle again: the community helps her to become more competent, which will finally enable her to help newcomers in the community, therefore becoming conscious of her learning and more self-confident in both performing the task and assuming new roles in the community.

Personal creations in citizen cyberscience come from a minority of people who are highly engaged in the project. They identify themselves as project volunteers and they feel motivated to help the project to work better and have confidence to share their ideas with others. The project forum is a key space where creative outputs are shared because it is through the community that creative individuals have an audience to share their ideas with and to receive validation for their efforts. Personal creations also help to deepen a volunteer's sense of identity, as it helps volunteers to find their place in a project, being known and appreciated by other members.

Discussion & conclusions

Citizen cyberscience projects typically have a skewed pattern of participation, where a small number of volunteers do the majority of the work [Eveleigh et al., 2014]. For some projects this works, and they are happy to find the “*super volunteers*” that are able to contribute consistently and submit good quality work [Causser and Wallace, 2012]. But other projects struggle to get enough volunteers to do the work, or desire more participants because they want to achieve educational as well as scientific goals. Previous research also indicates that volunteers' motivations are dynamic and can change over time [Rotman et al., 2012; Iacovides et al., 2013], e.g. a project might have a core group of committed volunteers now, but this may not be sustained over the project lifetime. These factors highlight the importance of understanding more about why volunteers participate and contribute in the way that they do.

In particular, we wanted to understand more about the potential benefits of participating in citizen cyberscience. We conducted 39 interviews (28 with volunteers, 11 with researchers) with the objective of exploring three main themes — motivation, learning, and creativity. In our results we present the MLC model (see Figure 4), which depicts a feedback loop between learning and sustained motivation and participation. We have also presented an overview of how volunteers learn through participation, the different kinds of learning outcomes, and the different kinds of personal creations.

Our thematic analysis revealed that volunteers are motivated to contribute more than once if they feel like they have an aptitude for the task, they enjoy participating in the task, and/or they enjoy participating in the activities surrounding the project (forums, chats). Barriers for engagement included finding the task difficult and/or boring, and lack of time due to other priorities, e.g. studying. The most dedicated volunteers appear to get into a rhythm of working. By participating regularly they stay up to date with project news, they gain greater aptitude for the project task, and they become increasingly familiar with other volunteers over time, becoming part of the core forum community.

Activities through which volunteers learn can be categorized according to two levels: at a micro level, that is direct participation in the task; and at a macro level, for example, use of project documentation, personal research on the Internet, and practicing specific roles in project communities. Generally, the more aspects volunteers participate in the project, the more they learn. However, this level of engagement is not correlated to purely quantitative investment in the task activities (duration of participation, number of hours in the project or number of tasks performed) but to the possibility of engaging in various activities beyond the task,

within or around the project (at the macro level), especially social activities in chats, forums or websites. Most learning in citizen cyberscience is unstructured, and either informal or incidental (not planned and not perceived as learning). "*Picking things up*" seems to be the way knowledge is spread in citizen cyberscience. Repeated practice allows volunteers to gain new skills and gain self-confidence in the quality of their contributions, thus feeling able to share with others on forums and help newcomers. This increase in project specific skills and knowledge precursors a potential change of status from a simple participant to a participant with specific responsibilities, such as moderating the forum or updating the Frequently Asked Questions (FAQs). A similar process takes place with respect to on-topic extra learning, scientific literacy and off-topic learning. For example, participants can start by asking questions about the nature of the project and the design of citizen cyberscience tasks, and then start reading both official and other documentation, doing translations for the community, developing tools, etc. These findings highlight the informal and social aspects of adult learning and stress the importance of learning through the indirect opportunities provided by the project: the main one being the opportunity to participate and progress in a project community, according to one's tastes and skills. This wide and unpredictable range of learning outcomes associated to self-directed participation into citizen cyberscience projects is convergent with recent conclusions on learning in informal environments [Lemke et al., 2015], and has implications on designing evaluation protocols: these should cover an extensive field of potential learning outcomes, open to unexpected learning outcomes beyond the scope of expected learning outcomes, in order to fit with the specificities of the projects' topic, structure, and community, and each participant's history, interests, life situation and engagement.

There are some similarities between the model presented and others within the literature, such as the Gaming Involvement and Informal Learning (GIIL) framework [Iacovides et al., 2014], though also some notable differences. While the former focuses on informal learning within the context of gaming, the latter considers learning in the context of citizen science projects (which may or may not be games). In terms of similarities, both models make distinctions between micro and macro level participation; as well as between how people learn and what they learn. More significantly, both are influenced by the communities of practice literature [Wenger, 1998] as they emphasise the iterative relationship between learning and identity and how this is reinforced through participation in a range of practices. However, while there is some overlap between how participants learn and learning outcomes e.g. learning through *external resources*, many of these categories have a different emphasis and due to the citizen science rather than gaming focus, our model includes categories such as scientific literacy. Further, the MLC model mentions additional facets of participant identity such as *feeling like a scientist*. Finally, the GIIL does not explicitly refer to people's motivations for participating in gaming practices nor to personal creations.

Personal creations are an important aspect of participation in citizen cyberscience projects. Volunteers who develop and share personal creations are motivated by their sense of belonging to feeling a particular project community and their desire to improve the project. In line with previous findings [Tinati et al., 2015], we found that the project forum was a key space where ideas and personal creations were shared. It is important to provide users with tools to communicate in order to supporting social learning, community building and sharing. Volunteers proposed

suggestions and built tools/resources in order to solve project problems. Community-enhanced gamification, forum discussions and artwork, provided excitement and enhanced the life of the community. Volunteers also shared the project with others via outreach activities, providing new ways for the community to grow. Creativity seems to be strongly related to engagement: it can optimize both an individual's activity and the project itself.

One of the strengths of our research is that we interviewed volunteers across a range of different citizen cyberscience projects (volunteer computing, volunteer thinking, and participatory sensing). In contrast to Curtis [2015], we found that learning did not appear to be related to the complexity of the task. Instead learning outcomes were mostly related to the engagement of volunteers in the social aspects of the project. For example, volunteer computing is typically thought of as involving little effort from volunteers [Haklay, 2013]; however, the BOINC volunteers we interviewed described having a very rich community life which motivated them to create competitions with other members. These findings demonstrate that volunteer involvement may turn out to be more complex than expected, especially when there is an active project community to provide additional excitement and engagement alongside the main task.

A further strength of our research is that it allows us to gain an insight into the reasons why volunteers may choose to stop participating. This is an important contrast to previous research studies, which tend to focus on exploring the motivations of those volunteers that are currently active in the project [Eveleigh et al., 2014]. Our findings reveal that data quality is something that volunteers are concerned about; in fact it is a reason why volunteers sometimes drop out of a project, because they are afraid of submitting incorrect data. These findings help to battle possible misconceptions that volunteers do not care about data quality, or are unaware of issues concerning data quality.

As the field of citizen cyberscience continues to grow, researchers are increasingly interested in identifying best practices for designing and managing citizen cyberscience projects, and studies such as ours provide valuable insights into the experiences of citizen cyberscience volunteers. Our study provides evidence that learning and creativity strengthen both the quality and length of individual participation. This obviously invites a further question: how does it impact the volume of participation? And, equally importantly, how should these opportunities be presented in order to minimise barriers to participation?

In future research, we will build upon our MLC model and explore how human-computer interaction and user-centred design practices can improve the experiences of volunteers. For example, how can we support volunteers in their learning and creative thinking? Based on our study, we suggest that the different types of citizen cyberscience have more things in common than things separate. When thinking about how to encourage learning, designers do not necessarily need to focus on whether it is volunteer computing, thinking or sensing, but rather how difficult it is to start contributing to the project, whether there is progression in the difficulty of the tasks, and whether volunteers received feedback about their contributions. Another commonality we found between the projects is the importance of community learning — this goes beyond simple task mechanics and may include on-topic learning and off-topic learning. Related to this, another

research direction would be to explore the social dimensions of engagement, learning and creativity, especially in relation to how participants adopt new roles and responsibilities within online citizen science communities.

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