Learning by volunteer computing, thinking and gaming: What and how are volunteers learning by participating in Virtual Citizen Science?

Conference or Workshop Item

Learning by volunteer computing, thinking and gaming:
What and how are volunteers learning by participating in Virtual Citizen Science ?

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Abstract

Citizen Science (CS) refers to a form of research collaboration that engages volunteers without formal scientific training in contributing to empirical scientific projects. Virtual Citizen Science (VCS) projects engage participants in online tasks. VCS has demonstrated its usefulness for research, however little is known about its learning potential for volunteers. This paper reports on research exploring the learning outcomes and processes in VCS. In order to identify different kinds of learning, 32 exploratory interviews of volunteers were conducted in three different VCS projects. We found six main learning outcomes related to different participants' activities in the project. Volunteers learn on four dimensions that are directly related to the scope of the VCS project: they learn at the task/game level, acquire pattern recognition skills, on-topic content knowledge, and improve their scientific literacy. Thanks to indirect opportunities of VCS projects, volunteers learn on two additional dimensions: off topic knowledge and skills, and personal development. Activities through which volunteers learn can be categorized in two levels: at a micro (task/game) level that is direct participation to the task, and at a macro level, i.e. use of project documentation, personal research on the Internet, and practicing specific roles in project communities. Both types are influenced by interactions with others in chat or forums. Most learning happens to be informal, unstructured and social. Volunteers do not only learn from others by interacting with scientists and their peers, but also by working for others: they gain knowledge, new status and skills by acting as active participants, moderators, editors, translators, community managers, etc. in a project community. This research highlights these informal and social aspects in adult learning and science education and also stresses the importance for 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.

Keywords

Informal learning, Incidental learning, Citizen Science, Adult learning, Adult development, Learning by Research

"Much of what people know about science is learned informally"[1]

Citizen science refers to a form of research collaboration that engages volunteers in contributing to empirical scientific projects. This participation can take several forms including: volunteer computing, volunteer sensing (data collection), volunteer thinking (data analysis and interpretation), participatory action research (Grey, 2009, Haklay, 2013).
The majority of citizen science projects that have emerged over the last decade are "virtual", i.e. engage participants in online tasks. Most of these projects either ask participants to help perform tasks that computers cannot do or for which "many eyes" are needed. Some of the most successful projects operate on a massive scale and rely on tens of thousands of participants, e.g. the 18 projects of the Zooniverse coalition attract over 800,000 participants. Some Citizen Science projects have been remarkably successful in advancing scientific knowledge. As one metric of scientific success, Dickinson et al. (2010) estimate that over 1000 peer-reviewed publications and technical reports have been produced using data from just eight large-scale projects (quoted by Shirk et al., 2012). While the main goal of such projects is "helping science", project initiators also aim to interest participants in their research and either implicitly or explicitly expect participants to learn something about the subject matter or research methods. However, so far little is known about what exactly people learn and how they learn in such projects. The aim of this research is to conduct a preliminary study of the different types of learning that occur within virtual citizen science projects.

1. Virtual Citizen Science as a learning tool?

Public participation in scientific research has become increasingly popular, thanks to technological and social changes (Haklay, 2013). Virtual Citizen Science (VCS) – as opposed to "classic citizen science" – is a unique form of computer-mediated interaction, where members of the public collaborate with professional scientists to conduct scientific research (Reed et al. 2012). There are a wide variety of VCS projects, all with their own research questions and tasks. Volunteers participate because they are intrinsically motivated (Rotman et al., 2012) to contribute to a scientific project by an interest in the topic, e.g. astronomy[2], protein-folding[3], brain-mapping[4], theoretical physics[5], volunteer computing[6]. It is commonly thought that VCS projects also result in participants learning through observation and engagement about the subject of research and experiencing the process of scientific investigation. This learning could occur both informally (intentional informal learning or

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[1] *Learning in the wild*, Nature, 464, 813-814 (8 April 2010).
[2] Galaxy Zoo. http://www.galaxyzoo.org/
Stardust@home. http://stardustathome.ssl.berkeley.edu/
[3] Foldit. http://fold.it/portal/
[4] Eyewire. https://eyewire.org/
[5] Test4Theory. http://lhcathome2.cern.ch/test4theory/
[6] BOINC. http://boinc.berkeley.edu/

incidental learning), and formally whenever scientists provide formal teaching to train volunteers. However, as of yet, only a handful of studies have investigated learning in VCS.

Learning in Citizen Science

While the contribution of volunteers to scientific data collection and analysis has been well documented, there is still limited research on how participation in Citizen Science projects may affect learning: "The growth in citizen science programs over the past two decades suggests that we need to evaluate their effectiveness in meeting educational goals" (Crall et al., 2012). When available, results on learning focus on effects of participation on scientific literacy (Bonney et al., 2009; Cronje et al., 2011; Crall et al., 2012; Price & Lee, 2013) and on content-knowledge (Jordan et al., 2011). Some projects also advocate changes in everyday behaviour (Jordan et al., 2011). A lot of these studies (except Price & Lee's study) deal with conservation projects, i.e. traditional citizen science as opposed to VCS.

A look at their results shows that the effects of participation on scientific literacy are difficult to assess: "In our study, participant knowledge of the nature of science and science-process skills did not change, despite explicit instruction" (Jordan et al., 2011). Trumbull et al. (2000) found no effect on scientific literacy with quantitative measures, however, qualitative analyses of 750 letters revealed that 80% showed evidence of some scientific inquiry among participants. Crall et al. (2012) also found no changes in science literacy or overall attitudes between tests administered just before and after a one-day training program, matching results from other studies. However, they found improvements in science literacy and knowledge using context-specific measures and in self-reported intentions to engage in pro-environmental activities. Cronje et al. (2011) also assessed the effect of invasive species monitoring training on the scientific literacy of citizen volunteers thanks to contextual multi-item instruments and they were able to demonstrate significant increases in the scientific literacy of citizen scientists. The authors conclude that "there remains little published evidence that citizen science experiences can improve the scientific literacy of participants", maybe due of the lack of specific evaluation tools, which would be able to detect the very specific learning at stake (p.136).

There is another promising focus for learning that relates to social involvement within VCS communities. Price and Lee (2013) report how volunteers' attitudes towards science and epistemological beliefs about the nature of science changed after six months of participation in an astronomy VCS project called Citizen Sky. Analysis of pre- and post-test data of 333 volunteers who participated for at least six months in the project reveals a positive change in scientific attitudes. Correlating these data with the participation paths of the subjects in the project, the researchers conclude that improvement in scientific literacy is related to participation in the social components of the program but not to amount of contributed data.

Gains in content knowledge may be easier to detect (Brossard et al., 2005). Jordan et al. (2011) report 24% knowledge increase of invasive plants, but simultaneously state that participation was insufficient (too short) to increase understanding of how scientific research is conducted. Participants reported increased ability to recognize invasive plants and increased awareness of invasive plants’ effects on the environment, but this translated little into behaviour regarding invasive plants.

Supporting learning and creativity in the Citizen CyberLab[7] project

The Citizen Cyberlab project (2012) aims to investigate learning and creativity in VCS, then implement the most effective design elements in future projects and evaluate their effectiveness. In this contribution we try to gain insights on *what* participants *can* learn and on *how* they learn within a set of contrasted VCS projects. We are interested in capturing all forms of learning, e.g., formal learning related to task achievement, informal learning about the research field, and incidental learning about various topics. The outcome of this qualitative exploratory research will be presented as initial typology of learning that can inspire both citizen science project design and further investigations.

2. Methodology and data collected

Exploratory interviews on usage, motivation, learning, creativity and sociability in VCS projects were combined with online observations in projects and forums to understand what kind of learning processes, if any, were occurring. 32 semi-structured exploratory interviews with participants in different types of VCS projects (volunteer computing, volunteer thinking and volunteer gaming) were conducted from December, 2012 to June, 2013. Three main projects were selected on the basis of their diversity, as they provided different kinds of tasks associated with various levels of volunteers' participation:

- volunteer computing activities, by analyzing volunteer involvement into the *BOINC* world of projects (http://boinc.berkeley.edu/), in which volunteers are asked to give free computing power for distributed calculations for scientific projects;
- volunteer thinking, by analyzing volunteer involvement into *Old Weather* (http://www.oldweather.org/), a transcription project from multiple partners including the The Met Office (the UK's National Weather Service), the UK and US National Archives, and the National Maritime Museum in London, in which volunteers are asked to transcribe logbooks from Royal Navy and US ships from a hundred years ago in order to investigate climate change;
- volunteer gaming, by analyzing *Eyewire* (http://eyewire.org/), a scientific "game to map the brain", provided by the Department of Brain and Cognitive Sciences at MIT, in which volunteers are colouring puzzles to map the 3D structure and connections of neurons in the retina of mice.

This paper will present the results from the thematic analysis (Braun & Clarke, 2006) of our exploratory interviews. This work entailed the following steps: full transcription of the interviews, anonymization of the transcripts, analysis of the transcripts using iterative reading and coding categories, comparison of our analyses in a 2 day data analysis workshop, and finally presentation and discussion of the preliminary findings with the Citizen CyberLab partners in a 2 hour interactive workshop.

[7] http://citizencyberlab.eu/

3. Results

The results demonstrate the variety of learning outcomes and learning paths in VCS, as well as the prevalence of unexpected and incidentallearning effects.

Learning happens in VCS

Most participants report experiencing learning effects due to their participation in VCS projects. These learning effects were often surprising for the volunteers. Some participants consider learning as an interesting but unexpected by-product of their contribution to science. For instance, when asked "Was learning initially an objective for you in the project?", one participant answers: *"A little bit, initially. I suppose I thought I might learn something, but I learned an awful lot more than I thought I would. I think my initial objective was, you know, this looks like something good to do, to help people find out about the climate, but then the more I got into it, the more I got into it [laughter]".* The motivation patterns of volunteers are out of the scope of this paper and will be dealt with in further work. However, our study so far strongly confirms that interest (defined as personal curiosity for science or for some specific scientific and social topics and desire to support science) is a key reason for involvement in VCS projects.

Some participants do engage in VCS projects with the explicit desire to learn and discover new things: "*Absolutely, learning is part of it. Every scientific project has a purpose and I like to find out what the purpose is."* Here learning appears to be at first related to curiosity, the wish to explore new things and new scientific domains. Discovering the purpose of a project by taking part offers an interesting intellectual challenge. Novelty and "coolness" of the projects are important motivational drivers. This initial expectation for learning opportunities is also related to another driver of the motivation of participants: the wish to use their free time in a productive way and not to waste it. This expectation is true at the collective level (contributing to a scientific project, efficiently and directly helping scientists) and at a personal level (pursuing at the best level their personal interests, learning, being part of an interesting, nice and prestigious community).

Learning happens also beyond the scope of initial discovery. Another participant reports: *"Absolutely, understanding it and then just being able to participate in it and then to learn from it, and just doing something I enjoy, made it even better".* For this participant, learning happens as a result of "doing" and extends the enjoyment of participation. They enjoy learning in a fun way. This enjoyment effect is reported by many participants: *"(as for me), I've learned lots and lots about different aspects of science or different sciences"; "(as for the society), I think people can really learn things in a fun way".* Another participant says: *"It's an easier way to learn things than do a course. Maybe you have a small part of it, but you pick things up on the way. I think that's also interesting for people to say well I tried the project and I didn't know much about it but now I'm very interested and I'm learning more and more about it. "*

Lastly, some participants report observing learning outcomes for themselves although they didn't consider learning as a primary goal. One participant says: *"Um learning was not a priority for me. It happens but I don't do it for that purpose."* Another answers: *"No it was not one of the reasons, I didn't realise what the opportunities would be when I joined. But it is something that has happened as a result of taking part".* Another one reports: *"It sure has become a learning experience. I think I just got into it a first because I'm fascinated with*

weather, it sounded kind of cool. Then I started playing around with it and I got hooked." This is particularly interesting for the study of informal learning, as it relates to unintentional learning in informal environments, a topic which requires additional naturalistic research.
So, learning happens, be it expected or not, as a product of participation in VCS projects. Is it possible to define more precisely what kind of learning happens in this context, and how? In our analyses, we identified six types of learning outcomes, which are related to different activities in which volunteers may engage online (see Fig 1):

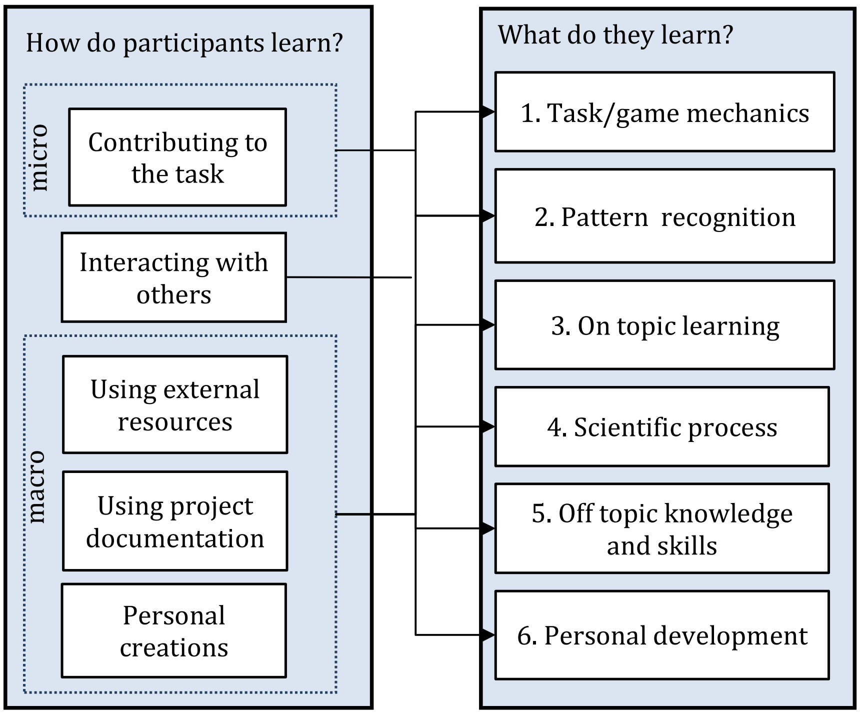

Figure 1: Learning in citizen science projects

With respect to "how they learn" we can distinguish between task related or "micro" learning (what participants learn when they engage in observing, classifying, solve puzzles, etc.) and off-task or "macro" learning, i.e. when participants engage in online forums, look up information on the Internet, study project documentation or augment the citizen science environment. Interacting with others can happen in both contexts and seems to boost learning. The distinction between micro and macro levels of involvement has been made in gaming research, where the term "macro-involvement" refers to player's general motivations for engaging with games" and the term "micro-involvement" refers to "the moment by moment instance of game play" (Calleja, 2007). Iacovides (2012) presents the Gaming Involvement and Informal Learning model, that distinguishes between how and what people learn through micro and macro level gaming. This conceptual distinction also exists within the game design community, in which the term "metagaming" refers to an important set of player's creative and collective activities in the game universe, outside of the game itself (Elias et al., 2012).

In the context of VCS, learning at the micro level mostly refers to learning the interface, e.g. participants will be able to solve increasingly difficult tasks. In addition they also develop pattern recognition capacities, i.e. become experts in “seeing” a structure in Eyewire. Learning at the macro level leads to all sort of learning that we can roughly divide into four kinds: learning about the respective science domain, about how research is conducted (the scientific process), and more surprisingly, various sorts of off-topic learning as well as in terms of personal development. We shall illustrate and discuss these categories in more detail below.

Six types of learning outcomes

(1) Task-Game mechanics

Our observations on the online forums and analyses of interviews suggest that participants firstly learn task/game mechanics, including the commands of the interface, the rules and concepts of the game.

For example, in the Eyewire project, people discover step by step the terms, concepts and rules of the game. Thanks to the videos presenting the project, online tutorials and training sequences, they learn the interface, the buttons to click and commands to activate to perform the task, rotate the 3D view, colour and unicolor the 2D view, erase if sections have been coloured by mistake, etc. (see Fig 2 for a summary of Eyewire's basic commands).

They also learn about the rules of the game**,** especially the credit system (how points are calculated), how this credit system relates to their performance, how they can use these results as a feedback tool, to improve themselves.

They also learn specific concepts instantiated in the game. For example, they learn what "cubes" or what "trailblazing" 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, participants may be actively in touch for the first time with the players' community behind. Learning at the project mechanics level distinguishes between newcomers and experienced players. The Frequently Asked Questions are typically answering uncertainties occurring at this level and disappearing with simple gaming experience. Learning can be observed at this level by the transformation of novices, who ask frequently asked questions, to more expert players, able to answer these questions.

Figure 1~~2~~: help summary for 3D and 2D controls in Eyewire

(2) Pattern Recognition

A subset of Citizen Science projects ask volunteers to analyse data, like pictures, soundtracks or texts, in order to classify them by identifying recurring patterns defined by the research team. In these kinds of projects, participants develop step-by-step 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, normal/abnormal, and develop tacit expectations. As a participant states in her interview: *"Now I can see"*. A participant in the Old Weather project explained that *"transcribing, you get a feeling of what is possible":* one develops expectations on how the weather could reasonably evolve in a given part of the world based on previous occurrences and temporal successions in logbooks. These expectations help the volunteers to get the meaning of difficult words, written with difficult-to-read handwriting or very pale ink. "Guessing" correctly is part of the transcribing process in that case, and knowledge of specific terms as well as expectations on what should normally follow help do the job confidently.

The similarity of this learning by repeated exposure to data and progressive building of pattern recognition skills, with some recommendations of experienced researchers to younger colleagues to "look" carefully and repeatedly at their data, may come to mind. In these cases, the very mechanisms of the project, which require volunteers to look repeatedly at similar data, put them in the position of developing these pattern recognition skills usually found in experts (Larkin et al., 1980). But they are limited to specific kinds of data - such as retina slices prepared with a specific method (Eyewire), or weather reports (Old Weather).

(3) On topic learning

On topic learning refers to content knowledge related to the scientific topic of the VCS project. Provided that the project mechanics integrate real scientific methods and concepts, participants may learn these by simply playing the game or performing the task - i.e., at the micro level. However, this topical learning mostly happens at the macro level, through an additional involvement of the participant beyond the task or game itself. In particular, participants search for various topics on the Internet. Internet search may be driven by problems arising at the task/play level, but it is most generally found when volunteers engage in side-activities in the project community, which complement the task/game itself: for example controlling data quality, discussing with others in forums, updating community forums, or translating project news.

Searching the Internet to solve the problems one encounters when performing the task is a common pattern of volunteers' activities. Internet searching is initiated either by curiosity based for example on *keywords or names* learnt doing the task, or by *problem-solving.* A participant in Eyewire reports having researched the Internet to find typical forms of Ganglion or Starbust Amacrine cells, in order to make better decisions when confronted to difficult choices in the game. He was actively looking for pictures in order to increase his recognition skills and take informed decisions in the game. In this additional Internet search process, participants learn a lot about topics which are directly related to the scientific focus of the project. For example, in Old Weather participants learn about geography of old times or specific historical events. A participant says for example: *"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 ? [laughter]".*

Participants in Old Weather explained how they search on the Internet to find the correct spelling of old places: *"When I'm transcribing, I often do try to look up the geographical type things to make sure I have them spelt correctly, but editing process is much more detailed because you want to make sure you've got it absolutely right. A lot of the geographical names have changed completely, from the first World War 'til now, obviously some of the countries have changed their names and that sort of thing but we're trying to pin down exactly what it is and get the first names right both in terms of what they were at the time and how they are now. So I've learned an awful lot about geography that I didn't know before".* Learning here appears to be driven by difficulty (the difficulty of spelling names correctly) and the wish to "get it absolutely right". Therefore, engagement in a community, in which the output of one's work will be used, is a major motivation for learning: volunteers want to do things right, not only for themselves, but also because their work is a valuable scientific contribution to a community of peers.

Some volunteers may have specific roles in the project, or in the participants' community. In the Boinc world, communities of volunteers have been built on the initiative of Citizen Scientists, on a local, usually linguistic, basis. Describing the social dynamics in these communities is out of the scope of this paper. However, these organizations 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 into their mother language to share them with the community; others read, summarize or translate research reports, news and papers. So doing, they may learn about protein folding, malaria or physics respectively in the Rosetta@home, FightMalaria@home and LHC@home projects. "Being in

charge" therefore appears to be a nice way to increase learning, as one performs additional work for the benefits of the whole community.
Content knowledge resulted not just from participating at the micro level (contributing to the task, playing the game), but from how the task motivated the participants to find out more about different related topics through interacting with others and consulting external resources such as the Internet or books. The project provides not only a context and the motivation (solving the task) to do so, but also basic “tools” like keywords, concepts or references, which serve as entry doors into the topic. One participant observes: *"you can tell they read the book because of their involvement in the project and not the other way around"*. Experience at the micro-level may provide the incentives for actively seeking more structured knowledge beyond the requirements of the project.

(4) Scientific literacy

Participants often describe potential learning through Citizen Science projects, especially at the collective, social level, in terms of increasing their scientific literacy. This scientific literacy is first linked to a general scientific culture: it is about better understanding what science does and how scientists work, which research questions they formulate nowadays and how they try to answer them. Talking about his experience in volunteer computing, one participant says: *"If the researchers give feedback to the volunteers on what they do, try to explain what they do, I think all this can improve the global scientific culture. Show citizens that science is useful. When they watch TV, they constantly hear about scientific catastrophes. These projects enable us to go beyond this vision of catastrophe science."* This participant adds: *"It transforms the short term vision. Experimenting 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."* Direct experience of scientific data and analyses may enable a large number of people to transform their views on science to incorporate some of its specific realities:
- Science takes time e.g: *"That’s really something I’ve learned, not that I thought it was instantaneous, but that science can take really a long time".*
- Failures are considered normal risks and contribute to exploration. Participants understand this through long-term participation, when they read research news and see how the project is involving to meet its goals.
- Science involves the use of rigorous procedures and controlled protocols. Awareness of these methodological requests appeared in a group of forum participants in Eyewire, following the suggestion to add comparison tools, which would enable them, in delicate cases, to compare their choices to those of other players, in order to ensure better quality of their responses. The research team did not want to implement such tools, arguing that they needed independent results. These discussions initiate the players to important scientific concepts, like data quality control or independent measures. The process of science may be further illustrated to volunteers when they become associated with scientific publications (or when researchers report about the process of writing their scientific publications). They discover for example the process of peer-review and revisions, and realize how long it takes to bring a paper to publication.

Participants also report that VCS projects offer opportunities for them to extend their scientific knowledge, as we will be discuss in the section on personal development below: *"Scientifically, it helped me discover new aspects of science, especially with space or medicine* *projects."* These effects can be appreciated for example, by the accessibility of popular scientific publications to volunteers: *"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 !".*

(5) Off topic knowledge and skills

Off topic learning refers to content knowledge or procedural skills exceeding the scope of the VCS project in several ways. Participants may develop knowledge and skills, which are not related to the topic under study, but still related to the indirect requests of the task or to the opportunities offered by the project.
Off topic skills reported in this research include:
- specific skills, tightly linked to the characteristics of the VCS project. In Old Weather, participants improve their handwriting reading skills due to the need to transcribe old maritime logbooks: *"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."* In volunteer computing, volunteers may improve their understanding of GPUs and Virtual Machines.
- general skills, reported in all three analysed projects. The two main skills mentioned in our research are related to (a) communication skills and (b) computer and web literacy.

This section will focus on these general skills as they may be partly transferable. For example, one of the participants in the volunteer computing projects is considering changing job, from postman to HTML developer, thanks to all the practical things he has been learning animating his volunteer computing community for years: *"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."*

(5a) Improving one's communication skills

Communication skills here refer to:
- *learning English for participants who are not native English speakers*: progress in English is linked to the fact that almost all projects online 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 improvement both through reading English documents and through interactions with the project community. Moreover, language barriers of their peers may even provide incentives for translating critical pieces of documentation on the project, tutorials, questions, or news. One participant explains that he got better thanks to this translation activity: *"Being able to help translating texts enables to better understand"*. Another one states: *"I did improve a lot in the last 5 years!"* Volunteers improve their English and get more confident in their communication skills in English. Commenting on being a translator in the Boinc community, a participant remembers his beginning: *"I told myself I can't do it, I didn't dare trying"*.

- *online communication skills*: volunteers learn how to use the discussion tools provided by the projects. The most common are discussion forums, usually moderated at least partially by expert volunteers, and chats. Volunteers get a chance through peer-guidance to learn the right way to ask questions, write answers, initiate and contribute discussions. A participant told us: *"I had never used a chat before"*. VCS projects provide here structured ways to get familiar with communication tools which are widely present on the Internet. Some projects also offer Wikis, which may help people learn how to contribute to wikis, but no such case was reported in our interviews.
- *community managament skills*: the biggest VCS projects sponsor volunteer-driven communities. Volunteers therefore get the opportunities to get their hands on the management of a community, which they could normally not have created by their own. This community deals with a real-life scientific project an dfrequently involves hundreds of participants from very diverse professional backgrounds and age ranges (from students to retired people). Community management activities observed in our data involves, among others: 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.

(5b) Computer and web literacy

Some volunteers report gaining knowledge and skills in the field of computer or web literacy. Let's consider the Web Literacy Standards as defined by the open source Mozilla's community (see Fig 3):

Figure 3: Mozilla's Web Literacy Standards (July, 2013 version)

Volunteers in almost all projects receive incentives and gain opportunities to learn at the *Exploring level: Navigating the Internet*, by intense Internet critical search practices (therefore improving their skills on the Search, Navigation and Credibility dimensions).
Volunteers in charge of updating project or community content on the web may get also some *Building skills*, especially in Composing for the web, HTML programming, CSS (Cascading Style Sheets) and Design and Accessibility.
Volunteers participating in online communities or collaborative content creation, or managing online communities, may also gain education on the *Participating on the Web* level, especially on the sharing and collaborating and community participation dimensions.

Volunteer computing projects have a specific educational impact for a small set of highly engaged volunteers on computer literacy. In principle, this kind of VCS only requests volunteers to download a software, which will then be run on their computer. However, many technical problems may arise, versions of the software get regularly updated according to the latests computer innovations, volunteers try to monitor and optimize what is happening on their computers, and they may face security or computing power issues. All these difficulties provide learning opportunities: *"Lots of people are reluctant to install on their computer some software that is running automatically. One is not very active at the beginning. At least this was my worry. I checked others' experiences on the forums, if some had had problems with it afterwards. I was a real beginner regarding my knowledge of computers. I had to get started on the computer domain... Thanks to this system, I learnt how to use my computer correctly".* Novices and experts seem to learn equally if they actively investigate the field: *"It motivates me to watch technology innovations. For example when the GPUs arrived on the market... I have always been fond of computers, but then one has other priorities in life and can't follow all these incredible changes... Volunteer computing helps me to stay up-to-date on the main computing evolutions".*

(6) Personal development

Some volunteers in VCS report important outcomes at a personal level, gathered here under the label "personal development". It includes:
- increasing one's self-confidence based on successful performance in the project tasks and additional tasks (like translations for the community),
- expanding one's interests, by discovering new topics of interests relative to science or to the community activities,
- extending one's social network,
- assuming new roles in a science-based community,
- doing creative works.

(6a) Self-confidence

The main output of participation to VCS may be the positive experience to contribute efficiently to a real scientific project. Volunteers experience their contribution as being valuable and also gain self-efficacy which in turn positively affects learning (Bandura, 1977). This contrasts to the usual understanding of science as an elitist, closed world.

This positive experience outsells other learning outcomes. A participant in Old Weather reports: *"I think to me the main learning is personal in terms of trying things out by doing it. So I've certainly learned more about Internet searching than I would otherwise have known. I now have an enormous stored geographic knowledge and place names from 100 years ago. And we have discussed this in the forum about what are we going to do with this obscure geographic knowledge of light houses on the northern and naval terminology which is no longer used [laughter] and so on. There must be some way we can pull this knowledge in the future [laughter]. You never know but...it's just I learned a whole world I didn't know existed and it's rather a shame that it looks like they're not going to put online the, that's it's unlikely that they're going to get the log books from WWII because that would've been fascinating".*

This quote sketches a virtuous circle: improving one's knowledge and skills by doing the task and sharing these in a community of peers help increase self-confidence, therefore ability to perform the task and wish to share.

The community supports the development of confidence and identity. Learning includes a meta dimension, it is about becoming competent in a field and knowing one is competent in a field, which often happens through the discovery that one is now able to help others. Here we have a virtuous circle again: the community helps one become more competent, which will finally enable him or her to help newcomers in the community, therefore becoming conscious of one's learning and more self-confident in both performing the task and assuming new roles in the community. A participant in volunteer computing reports: *"I don't want to run us down but we might suffer a bit from exclusion because of our passion... Science... It is not easy to share. Especially for novices. We are not expert. We are eager to know, but we don't have the training for it. These Boinc projects help us get this knowledge. (...). And then we try to make things accessible on the forum for a 10 years-old kid. I thought if my daughter comes and visits this forum, she should get the essence of it without having to ask what does this mean Daddy or asking her teacher!"*

(6b) Expanding one's interests

Participation to VCS is frequently reported as a way to "open one's mind": *"Um, 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".*

On a scientific level, volunteers, who engage in VCS because they are interested in a specific topic, usually expand their initial interests in the process: *"For me, it has given me a new interest, that I wouldn't have otherwise have had".* One says: "*You would have talk to me about protein folding ten years ago, I would have told you what is this silly thing*?" One participant adds: *"I was passionate by science since I was a small boy. But I had not the means to do it".*

This increased scientific engagement may open doors to new, unexpected activities, which further strengthen the involvement of volunteers in the approach: "*I've learned lots and lots about different aspects of science or different sciences. Going to a couple times a year to London or Oxford to meet people (...), being interviewed [laughter] (...) that's really funny* *and I never thought I'd be doing this and getting to be a co-author in a scientific paper, well I never dreamed I would be a part of that".*

(6c) Extending one's social network

To the question "Would you say that some people on the forum are friends?", the most engaged volunteers generally answered "yes", "almost", "to some extent", "at least online friends": *"Almost. They are in the process of becoming friends. 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."* Friendship is a by-product of active involvement at the meta level, of shared responsibilities in community activities. Volunteers with close links come to communicate not only publicly or semi-publicly via the project communication tools (forum or chat), but also in private via a variety of one-to-one media: phone, video conference, instant messaging, or email.

Sometimes, groups of people who are active online decide to meet "in real life", usually for special, public or private, events. A large scientific society meeting may serve as a meeting point: volunteers will join and held a parallel social track, for example meet in a pub to socialize around the project. A subgroup may also organize a private meeting on a specific topic (for example, Open Source Development). The most common experience in such cases is a feeling of excitement and relief: excitement (and sometimes a bit of fear) in the perspective of meeting these online friends at last, and relief, as they experience the same familiarity and ease of relations in-person as in their online interactions. Online pseudonyms are used equally with real names in such meetings.

(6d) Assuming new roles in a science-based community

We have been highlighting the critical role of communities, and community communication tools like forums, in the learning potential of VCS. To some extent (with the restriction however that they are not professional arenas), VCS projects can be compared to communities of practice (Lave & Wenger, 1991), in which participants gain knowledge, as well as they experience a change in their professional identity, by participating step-by-step in a community of shared interests. The most commonly available roles to take include:

- Roles related to community management in the forum: updating the forum, translating news, project presentations, tutorials and reports, organizing content (editing), sharing the latest information, answering to questions, initiating discussions, commenting, moderating exchanges, animating teams, recruiting for special roles, organizing internal and external challenges...
- Roles related to the quality control of the data: editing, informing on quality issues, sharing experience and training volunteers, etc.
- Roles related to the continuous improvement of the project: suggesting improvements and participating in their development, programming (modding), creating tutorials, etc.

(6e) Opportunities for creative work

Creativity will not be dealt with in this paper and we will just mention here that creative works performed in the context of VCS provide opportunities for learning as well as for identity changes. A few examples include:
- programming software which automatically detect and answers Frequently Asked Questions in the chat to improve the gaming experience in the Eyewire project,
- designing TShirts, logos and badges for the community,
- or collaboratively creating research presentations and tutorials to promote the project: *"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."*

A provisional summary typology of learning outcomes

From the interview data we can abduct six large categories of learning outcomes.

Type 1 (project mechanics) and type 2 (pattern recognition) are closely related to the task. Their acquisition is required in the context of the project to ensure good performance. Type 3 (on topic learning) and type 4 (scientific literacy) are on topic, but not necessary to get the task done. Their acquisition may be encouraged in the context of the project but they are usually acquired by additional involvement into the project community. Type 5 (off topic skills) and type 6 (personal development) cover a wide range of skills that are not related to a specific citizen science field. They are unexpected outputs of heavy involvement in the projects.

Type	examples	formal (required)	informal/ incidental (encouraged)	informal/ incidental (individual)
1.project mechanics		xxx	x	
2. pattern recognition		xx	x	
3. on topic extra learning		x	xx	x
4. scientific literacy		x	xx	
5. off topic skills	languages, communication, community management skills, ICT literacy		xx	xxx
6. personal development	self-confidence, new interests, networking		x	xxx

Table 1: A provisional typology of learning

5. Discussion

The importance of informal and incidental learning

We documented six types of learning outcomes. Most learning is unstructured, either informal or incidental (not planned and not perceived as learning). "Picking things up" seems to be the way knowledge is spread in VCS. Participants seem to accumulate "small pieces", "small things", "the practical part of my curriculum"...

Comparing the three projects we also found that observed learning outcomes do not appear to be related to the complexity of the tasks. They appear to be mostly related to the engagement of volunteers in the social aspects of the project, i.e. the life of the community. For instance, an interviewed participant in the BOINC project preferred volunteer computing to volunteer thinking or gaming since the computer works on its own and he could dedicate his time to other more creative tasks, such as using time to monitor his computer/ investigate research projects/ read news and papers/ answer messages / support newcomers/ initiate discussions / organize challenges, in relationship to the community. As his time is limited, he would not like to reduce these dimensions to spend more time doing "active" contributions to volunteer thinking projects. We may have to rethink the postulate that participants' learning is increasing along the line of the "volunteer computing, sensing, thinking, extreme citizen science" scale.

Connecting learning outcomes and interaction with other volunteers

Let's recall that our initial results show that most learning in VCS is inherently social and informal and thus corroborate results from Price and Lee (2013). Some of the most spectacular occurrences concern various forms of personal development.

Firstly, learning may happen through direct exchanges with scientists in forums and chats or thanks to communication of the scientists addressed to the volunteers (blog posts, videos, wikis, papers, feedback on results). A second important type of social learning concerns direct or indirect exchange with peers: through direct exchanges in a personal network, through collaboration on problem-solving in team work, through efforts to achieve a better performance that is evaluated and publicized by the system, and through creative participant built add-ons to the existing systems (programming or community management). A third important type concerns extraneous challenges and roles of the VCS project that create opportunities for learning. For example, French-speaking participants in the Boinc community engage into heavy translation jobs for their peers since most projects presentations, tutorials and results are in English. Similarly, difficulties to make the software work on participant's computers strengthen community links. Changes in participation status open new opportunities for activity on all these levels, therefore new opportunities for learning. Here people are not only learning FROM others, by interacting with them in forums and chat, asking and answering questions, comparing results... but also FOR others: by assuming responsibilities in a community, which are a strong driver for sustained and highly-qualitative participation.

Discussing identity changes, when a happy few group of volunteers assume intermediary positions in between the large group of contributors and the scientific team, is out-of-scope of this paper. However, we can postulate that the existence of this kind of group contributes a lot to the success of a project. Further work will investigate and present the relationship between engagement in community and motivation, sociability and identity.

6. Conclusion

This exploratory research highlights learning dimensions in VCS that were not previously identified in a systematic way. It found a wide range of mostly informal learning outcomes, opportunities and mechanisms. A lot of learning seems to be "diffused" and unstructured, i.e. participants learn many "unplanned small things", picking them up from their engagement in VCS tasks or communities. However, these "small things" combined can lead to substantial learning in the dimensions of task/game mechanics, pattern recognition, on-topic or off-topic learning, scientific literacy or personal development. This research also highlights the critical role of communities in learning: volunteers learn by interacting with others, but also by assuming specific social roles. The social dimension is a motivational driver for sustained participation. It provides as well developmental opportunities for a small set of volunteers. VCS projects therefore offer both direct and indirect opportunities: Volunteers contributing to the project may acquire knowledge and skills related to the scope of the scientific project, and have the possibility to assume roles in communities that they would not have been able to create themselves. From a practical point of view, this typology supports a structured approach for learning-centered design of VCS. In particular, supporting learning in VCS environments requires paying close attention both to the design of the project itself and to these indirect mostly community-related opportunities.

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