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Citizen Science and Volunteered Geographic Information – overview and typology of participation

Abstract
Within Volunteered Geographic Information (VGI), Citizen Science stands out as a class of activities that require special attention and analysis. Citizen science is likely to be the longest running of VGI activities, with some projects showing continuous effort over a century. In addition, many projects are characterised by a genuine element of volunteering and contribution of information for the benefit of human knowledge and science. They are also tasks where data quality and uncertainty come to the fore when evaluating the validity of the results.

This chapter provides an overview of citizen science in the context of VGI – hence the focus on geographic citizen science. This chapter highlights the historical context of citizen science and its more recent incarnation. It also covers some of the cultural and conceptual challenges that citizen science faces and the resulting limitation on the level of engagement. By drawing parallels with the Participatory Geographic Information Systems (PGIS) literature, the chapter offers a framework of participation in citizen science and concludes with the suggestion that a more participatory mode of citizen science is possible.

Keywords: Citizen Science, Participation, Participatory GIS, Ladder of participation

Introduction
Volunteered Geographic Information (VGI), coined by Goodchild (2007), encompasses a wide range of activities and practices, ranging from the ‘fun’ activities of locating summer holiday photographs (Turner 2006) to focused surveying in the aftermath of an earthquake (Zook et al. 2010). Within these practices, there is a subset that falls into the category of citizen science – the involvement of non-professional scientists in data collection and, to some extent, its analysis. While it is possible to try to formulate a definition that delineates the boundaries of what should or should not be considered citizen science, a much more fruitful approach is to understand the general properties of citizen science and its overlap with VGI. As we shall see, not all citizen science is geographic, that is, involving a project in which a location on Earth plays an important role. Once the differentiation between the geographic and non-geographic projects is clarified, we can focus on the former, as they include an element of VGI, by necessity.

Before turning to citizen science itself, it is worth noticing, in the context of this book, how the different contextualisation of VGI illuminates aspects that might go unnoticed or unexplored otherwise. Thus, VGI can be seen as a way of producing geographical information and as a tool for updating national geographical databases (Goodchild 2007; Antoniou, Haklay & Morley 2010) in which case the appropriate context is spatial data quality and the production of geographical information. When it is viewed within the context of critical, participatory or feminist Geographic Information Systems (GIS) (Elwood 2008), questions about the nature of the participation, power relations and other societal aspects of VGI are opened – thus, the process of creating VGI is becoming as important as analysing the product. When Budhathoki et al. (2010) look at the reasons for participation in leisure, volunteering and contribution to open source projects in the context of VGI, they highlight that the behaviour of participants and the reasons that lead to their involvement are important elements of VGI. Other interpretations and contextualisation of VGI provide their own prism to the activities of participants and the resulting products. Because VGI is an area that requires a socio-technical analysis, these prisms are valuable in helping to understand the phenomena and to consider the relevant applications of its products. The use of citizen science provides another such prism, highlighting how VGI operates within scientific knowledge production.

In the current chapter, we start with an overview of the field and changes that have occurred to it in the past decade following the growth of the Internet in general, and the World Wide Web (Web) in particular, as a global communication platform. Next, the enabling factors and trends are briefly outlined and explained. Following this review, the characteristics of geographic citizen science are reviewed based on current evidence. We then turn to the intriguing aspect of cultural challenge to existing scientific practices that citizen science puts forward. Finally, by drawing on established practices in participatory GIS, a framework of participation in citizen science is offered and its implications are analysed.

Citizen Science

As noted before, while the aim here is not to provide a precise definition of citizen science with rigid boundaries, a definition and clarification of the core characteristics of citizen science is needed. Therefore, we define it as the scientific activities in which non-professional scientists volunteer to participate in data collection, analysis and dissemination of a scientific project (Cohn 2008; Silvertown 2009). People who participate in a scientific study without playing some part in the study itself – for example, volunteering in a medical trial or participating in a social science survey – are not included in this definition. At the same time, the core issue of 'who is a scientist' is left deliberately blurred. This is because it is easier to identify professional scientists as those that are employed to carry out scientific work or investigation. With unpaid scientists, the situation is more complex – many will not define or identify themselves as scientists even if they are carrying out significant work within the scientific frameworks of data collection and interpretation. Others will use the qualification of amateur scientist to describe themselves, or a similar definition such as bird watcher. However, for our purpose, scientists are all the active participants in a scientific project.

It is important to notice that there are boundaries, albeit fuzzy, of what should be considered a citizen science project. While it is easy to identify a citizen science project when the aim of the project is the collection of scientific information, as in the recording of the distribution of plant species, there are cases where the definition is less clear-cut. For example, the process of data collection in OpenStreetMap or Google Map Maker is mostly focused on recording verifiable facts about the world that can be observed on the ground. The tools that OpenStreetMap mappers use – such as remotely sensed images, GPS receivers and map editing software – are scientific instruments. With their attempt to locate observed objects and record them on a map accurately, they follow in the footsteps of surveyors who followed scientific principles in their work such as Robert Hooke, who also carried out extensive survey of London following the fire of 1666 using scientific methods – although, unlike OpenStreetMap volunteers, he was paid for his effort. Finally, cases where facts are collected in a participatory mapping activity, such as the one that Ghose (2001) describes, should probably be considered citizen science only if the participants decided to frame it as such. The framing of the activity is important, because in citizen science the expectations are that the data collection will follow a certain protocol and that data analysis and visualisation will be carried out according to established practices. Under a citizen science framing, the activity will focus on recording observations rather than highlighting community views or opinions.

Notice also that, by definition, citizen science can only exist in a world in which science is socially constructed as the preserve of professional scientists in academic institutions and industry because, otherwise, any person who is involved in a scientific project would simply be considered a contributor and, potentially, a scientist. As Silvertown (2009) noted, until the late 19th century, science was mainly developed by people who had additional sources of employment that allowed them to spend time on data collection and analysis. Famously, Charles Darwin joined the *Beagle* voyage, not as a professional naturalist but as a companion to Captain FitzRoy. Thus, in that era, almost all science was citizen science albeit mostly by affluent gentlemen and gentlewomen scientists. While the first professional scientist is likely to be Robert Hooke, who was paid to work on scientific studies in the 17th century, the major growth in the professionalisation of scientists was mostly in the latter part of the 19th and throughout the 20th century.

Even with the rise of the professional scientist, the role of volunteers has not disappeared, especially in areas such as archaeology, where it is common for enthusiasts to join excavations, or in natural science and ecology, where they collect and send samples and observations to national repositories. These activities include the Christmas Bird Watch that has been ongoing since 1900 and the British Trust for Ornithology Survey, which has collected over 31 million records since its establishment in 1932 (Silvertown 2009) – see Figure 1. Astronomy is another area in which amateurs and volunteers have been on a par with professionals when observation of the night sky and the identification of galaxies, comets and asteroids are considered (BBC 2006). Finally, meteorological observations have also relied on volunteers since the early start of systematic measurements of temperature, precipitation or extreme weather events (WMO 2001).

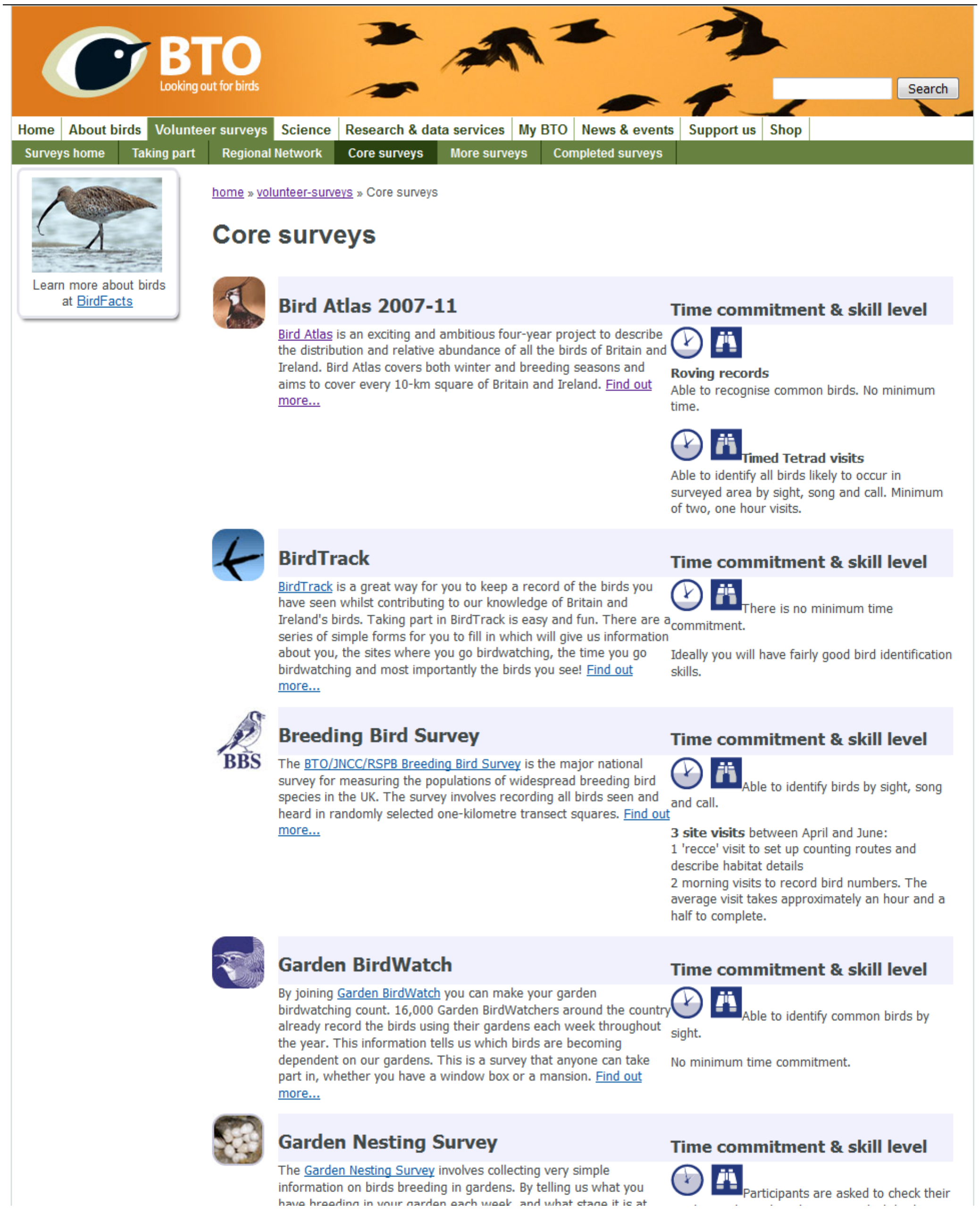

Figure 1 – British Trust of Ornithology listing of potential engagement projects and level of engagement

This type of citizen science provides the first class of 'classic' citizen science – the 'persistence' parts of science where the resources, geographical spread and the nature of the problem mean that volunteers sometimes predate the professionalisation and mechanisation of science. There activities usually require a large but sparse network of observers who work as part of a hobby or leisure activity. This type of citizen science has flourished in specific enclaves of scientific practice, and the progressive development of modern communication tools made the process of collating the results from the participants easier and cheaper, while inherently keeping many of the characteristics of data collection processes close to their origins.

A second type of citizen science activity is environmental management and, even more specifically, within the context of environmental justice campaigns. Modern environmental management includes strong technocratic- and scientific-oriented management practices (Bryant & Wilson 1998; Scott & Barnett 2009) and environmental decision making is heavily based on scientific environmental information. As a result, when an environmental conflict emerges – such as community protest over a noisy local factory or planned expansion of an airport – the valid evidence needs to be based on scientific data collection. This aspect of environmental justice struggle is encouraging communities to carry out 'community science' in which scientific measurements and analysis are carried out by members of local communities so they can develop an evidence base and set action plans to deal with problems in their area. A successful example of such an approach is the 'Global Community Monitor' method to allow communities to deal with air pollution issues (Scott & Barnett 2009). This is performed through a simple method of sampling air using plastic buckets followed by analysis in an air pollution laboratory before, finally, the community is provided with instructions on how to understand the results. This activity is termed 'Bucket Brigade' and was used across the world in environmental justice campaigns. In London, community science was used to collect noise readings in two communities that are impacted by airport and industrial activities. The outputs were effective in bringing environmental problems to the attention of decision makers and regulatory authorities (Haklay, Francis & Whitaker 2008). As in 'classic' citizen science, the growth in electronic communication enabled communities to identify potential methods – e.g. through the 'Global Community Monitor' website – as well as find the details of international standards, regulations and scientific papers that can be used together with the local evidence.

However, the emergence of the Internet and the Web as a global infrastructure has enabled a new incarnation of citizen science, which has been termed 'citizen cyberscience' by Francois Grey (2009). As Silvertown (2009) and Cohn (2008) noted, the realisation to scientists that the public can provide free labour, skills, computing power and even funding, and the growing demands from research funders for public engagement, all contribute to the motivation of scientists to develop and launch new and innovative projects. These projects utilise the abilities of personal computers, GPS receivers and mobile phones to double as scientific instruments. Within citizen cyberscience, it is possible to identify three subcategories: volunteered computing, volunteered thinking and participatory sensing.

Volunteered computing was first developed in 1999, with the foundation of SETI@home (Anderson et al. 2002), which was designed to distribute the analysis of data that was collected from a radio telescope in the search for extra-terrestrial intelligence. The project utilises the unused processing capacity that exists in personal computers and uses the Internet to send and receive 'work packages' that are analysed automatically and sent back to the main server. Over 3.83 million downloads were registered on the project's website by July 2002. The system on which SETI@home is based, the Berkeley Open Infrastructure for Network Computing (BOINC), is now used for over 100 projects, covering physics, processing data from the Large Hadron Collider through LHC@home; climate science with the running of climate models in climateprediction.net; and biology in which the shape of proteins is calculated in Rosetta@home.

While volunteered computing requires very little from the participants, apart from installing software on their computers, in volunteered thinking the volunteers are engaged at a more active and cognitive level (Grey 2009). In these projects, the participants are asked to use a website in which information or an image is presented to them. When they register onto the system, they are trained in the task of classifying the information. After the training, they are exposed to information that has not been analysed, and are asked to carry out classification work. The Stardust@home project (Westphal et al. 2006), in which volunteers were asked to use a virtual microscope to try to identify traces of interstellar dust, was one of the first projects in this area, together with the NASA ClickWorkers that focused on the classification of craters on Mars. Galaxy Zoo (Lintott et al. 2008), a project in which volunteers classify galaxies, is now one of the most developed ones, with over 100,000 participants and with a range of applications that are included in the wider Zooniverse set of projects (see http://www.zooniverse.org/).

Participatory sensing is the final and most recent type of citizen science activity. Here, the capabilities of mobile phones are used to sense the environment. Some mobile phones have up to nine sensors integrated into them, including different transceivers (mobile network, WiFi, Bluetooth), FM and GPS receivers, camera, accelerometer, digital compass and microphone. In addition, they can link to external sensors. These capabilities are increasingly used in citizen science projects, such as Mappiness in which participants are asked to provide behavioural information (feeling of happiness) while the phone records their location to allow the linkage of different locations to wellbeing (MacKerron 2011). Other activities include the sensing of air quality (Cuff 2007) or noise levels in the application NoiseTube (Maisonneuve et al. 2010) by using the mobile phone's location and the readings from the microphone.

Before turning to the context and drivers of the current resurgent citizen science, it is noteworthy that other typologies of citizen science are offered by Cooper et al. (2007), Wilderman (2007), Bonney et al. (2009) and Wiggins and Crowston (2011). These classifications are highlighting aspects such as the level of informal science education, the involvement of participants in various aspects of research activity or the purpose of the project. This is expected in an emerging field, where similarly to VGI, researchers are scanning the field and suggesting ways to understand the landscape.

Context and Drivers

The general trends that ushered in the Web Mapping 2.0 era (Haklay, Singleton & Parker 2008; Goodchild 2007) are also part of the drivers that allowed the recent growth in citizen science in general, and citizen cyberscience in particular. These factors include the increased availability of higher capacity domestic Internet connections, and the reducing costs of computers and sophisticated mobile devices; the reduced costs of computer storage and the availability of extra storage capacity on personal computers that make it possible for participants to store and process large amounts of data without major implications to their own activities; the continued development of Internet technologies and standards such as eXtensible Markup Language (XML) that facilitate the transfer of information between computers; the increased accuracy of the Global Positioning System (GPS) since 2000 and the subsequent reduction in cost of receivers; and the growth of sophisticated Web applications that enable rich interaction by their users, allowing for applications such as the virtual microscope that was used in Stardust@home.

However, these general and mostly technological factors are only part of the trends that led to the blossoming of citizen science. As important are the social trends that enabled it. The main factor that needs to be considered is the growth in the population of well-educated individuals, with many millions of people who have studied to higher education degree level in science or engineering but do not use their scientific knowledge in their daily life. Moreover, with the increase in the demands of secondary education, many school leavers are equipped with basic scientific knowledge that is sufficient to make them effective participants in citizen science projects. For many of these people, education provided a starting point for an interest in science, which is not fulfilled in their daily activities. Thus, citizen science provides an opportunity to explore this dormant interest – while the educational attainment means that the scientists who design the project can assume a basic understanding of principles by the participants.

To this, we should add the increase in leisure activities and the reduction in working hours that has occurred in many advanced economies over the past four decades. Before the growth in electronic communication, hobbies were limited to private activities or occasional gatherings of a small group of enthusiasts. The ability of the Web to accommodate narrow interests and to allow a highly distributed network of individuals to share and discuss their interests is especially important for such activities. It allows for the creation of websites, mailing lists, and other ways in which these enthusiasts can come together and share experience, or join forces in working on scientific data collection or analysis.

Notice that together, the drivers are pointing to inherent bias in the socio-economic make up of citizen science, as the participant is highly likely to be living in an advanced economy and to be a member of the middle-class, thus to have the education, technical skills, access to resources and infrastructure that facilitates the participation in these activities.

Geographical Citizen Science

Against the backdrop of general citizen science, we can identify a specific subtype of activities that can be termed 'Geographical Citizen Science' and therefore fall within the definition of VGI. Geographical citizen science includes projects where the collection of location information is an integral part of the activity. It should become clear from the overview above that a significant part of the information that was and is collected through 'classic' citizen science, community science and citizen cyberscience projects is geographical – as in the location of observations in the Christmas Bird Watch, or the recording of noise along a given route in NoiseTube (Maisonneuve et al. 2010). Yet, in the past, the location was usually approximated, and sometimes given in grid co-ordinates of only 100-metre, or even 1-kilometre, accuracy, which meant that linking observations to a location could be tricky and highly uncertain. Even though location technology is increasingly available through Personal Navigation Devices (PND), GPS receivers and mobile phones, it is important to remember that, because of their affordance (in the sense of familiarity and ease of use, as in Norman 1990), paper maps remain a very effective medium for data collection. This has been shown in citizen science studies in London as well as in the integration of paper mapping activities in OpenStreetMap through Walking Papers (Migurski 2009). As long as the data collection media supports accurate geographic location, the project can result in high-quality geographical citizen science.

The first important characteristic of geographical citizen science is to understand the role of the volunteer. The role can be active or passive. An active contribution happens when the participant is expected to consciously and actively contribute to the observation or the analysis, as in the case of taking an image of an observed species, tagging it and sending it electronically to the project's hub. A passive data collection can happen when the contributor is acting more as an observation platform and the data are gathered without active engagement, for example, when a person volunteers to be tagged by a GPS receiver to monitor daily walking activity or replaces a memory card and batteries in an automatic digital camera that is installed on a deer track (Cohn 2008). A further differentiation can be made between geographically explicit and implicit citizen science projects (Antoniou, Haklay & Morley 2010). In geographically explicit projects, the activity is aimed at collecting geographical information, for example, in the British Trust of Ornithology project a participant is required to record a specific location of where the observation is taking place. In geographically implicit projects, the aim might be to collect images of different species, and some of the images will arrive with location information (geotagged), but the aim of the project is not to collect geographical information.

These different schemes will have an impact on the need to motivate and engage the participants and the level of training and knowledge that is required from them. In addition, different schemes will influence the ability to secure quantitative and qualitative information. While all forms can support the collection of some quantitative information, only the active and geographically explicit projects are likely to provide meaningful qualitative information such as descriptions of personal perceptions or textual descriptions of the place where the observation was recorded.

Research into the motivation and the spatial characteristics of VGI (Budhathoki, Nedovic-Budic & Bruce 2010; Coleman, Georgiadou & Labonte 2009; Haklay 2010), as well as studies of Wikipedia and citizen science projects (Nov, Arazy & Anderson 2011), is providing some guidance on what it is possible to achieve with geographical citizen science. What we know, so far, is that citizen science is a 'serious leisure' activity and that the most likely participants will join with some existing interest in the subject, and will be keen to learn more. They will be predominantly male, well educated and from higher brackets of the income scale, which gives them both the time capital to participate in the activity and the financial resources for specialist equipment and/or participation in field work. There will be 'participation inequality' with some participants contributing a lot, while many others contribute a little.

The areas that can be covered well by geographical citizen science will be areas with a high population concentration or high level of outdoor activity such as popular national parks. Coverage of other areas requires special planning and creation of suitable motivational schemes, including monetary ones, or reliance on a smaller pool of volunteers. There will also be temporal aspects to data collection, with summer months, weekends and daytime being the more popular times in which participants engage in data collection activities.

All these means that the data are essentially heterogeneous, and it is important to remember that the data quality will vary according to the number of volunteers who work on the data and the particular knowledge of each volunteer. Thus, the data should not be treated as homogeneous and complete where a quality statement can be attached to the whole assemblage but, rather, localised measures must be used. While all these aspects of geographical citizen science have an impact on the type of research questions and scientific challenges that can be answered through utilisation of suitable schemes, there is a potentially more significant challenge hindering this use of citizen science. This issue is more to do with the contemporary culture of science than with the putative value of citizen science itself.

Culture of Science Problems

The story of modern science is often told by highlighting the increased precision and accuracy with which information is obtained and analysed (e.g. Bryson 2004). In experimental science the instruments and devices were designed over the years to provide better accuracy, and complex experimental protocols were created to ensure that the level of uncertainty associated with measurements was reduced.

While it is well recognised that different academic disciplines have their own culture and specific practices (Latour 1993), such as the practice of double blind studies in medicine but not in other areas that research human subjects, the issue of dealing with uncertainty has been central to many areas of science, including geographic information science (see Couclelis 2003).

Interestingly, the attempt to eliminate uncertainty is especially prevalent in areas in which science is used in practical applications such as engineering or environmental management. Due to organisational reasons and policy (King & Kraemer 1993), protocols are enshrined in regulations and become 'the correct way of doing science' with rigid protocols, some parts of which are arbitrary.

The strive to eradicate uncertainty (or at least reduce it) and the development of complex protocols are at the heart of the cultural issue that is leading to suspicion, derision and dismissal of citizen science as a valuable method of scientific data collection. The mistrust of citizen science is, as noted in the opening, based on the view that science is best left to scientists, and it requires rigour, knowledge and skills that only professional scientists develop over time. As Silvertown (2009) noted, 'The apparent underrepresentation of citizen science in the formal literature probably has two causes. First, the term itself is relatively recent, and in fact hundreds of scientific papers have resulted from the data collected in Christmas Bird Counts and other long-running volunteer monitoring programmes. Second, **projects that fit uneasily into the standard model of hypothesis-testing research are written about only in the grey literature, or even not at all**;' (p. 471, emphasis added). This is also highlighted in Holling (1998) who emphasised that there are two cultures of science, and that citizen science by necessity belongs to the type of science that incorporates uncertainty and highlights integrative approaches. Interestingly, suspicion of VGI follows along the lines of what Holling identified in the area of ecology over a decade ago. Despite the evidence that VGI can be as accurate as professional data (Haklay 2010; Girres & Touya 2010), mistrust of VGI as a useful source of geographical information is common among professional users (e.g. Flanagin & Metzger 2008).

What is forgotten by those who oppose citizen science is the development of instrumentation and its impact on the balance of knowledge and skills that are required by the operator, as well as the level of motivation, dedication and attention to detail of volunteers. Scientific instrumentation has evolved tremendously over the past 350 years, if we take the invention of instruments such as Hooke's microscope in 1663 as an indication of the development of modern scientific instruments. Since then, the instruments have improved enormously in terms of their observational power, their accuracy and precision. However, until fairly late in the 20th century, they demanded a significant amount of theoretical and practical knowledge to operate them effectively. A great deal of professional judgement was required to balance the accuracy of a calculation with the practical aspects of conducting research. Consider, for example, that many calculations for NASA's moon missions were carried out with slide rules, where experience and judgement is necessary to decide if the calculations are satisfactory.

The computerisation and miniaturisation of scientific instruments, especially in the past 20 years, have changed this equation. Now, the humble GPS receiver encapsulates knowledge and procedures that are highly complex and is capable of calculating them with good precision without any intervention from the user. The GPS satellites themselves also encapsulate significant amounts of scientific knowledge and understanding. For example, William Roy spent about 6 weeks and engaged a team of 12 men to measure the 5-mile baseline of the English triangulation system with an accuracy of 2.5 inches. Today, a single person, equipped with a good quality GPS receiver and a mobile phone, can achieve a similar fit in less than a day. The sophistication of the equipment, and, more importantly, the science that is integrated into the computational parts of it, enables this.

The ability of equipment to provide accurate and precise measurement is central to the ability of volunteers to provide reliable scientific information, especially when these instruments are used in tandem with their personal knowledge and commitment. For example, research in the USA has shown that citizen scientists identified crab types correctly 95% of the time (Cohn 2008). Importantly, the basic understanding of scientific principles and methods, which are now routinely taught at school level, means that the participants in the research have an understanding of what is required of them and what is needed to take a reliable scientific measurement. What is more, because of this basic knowledge, they can carry out the observation without supervision and with very little training. Citizen scientists show significant commitment to the topic and are as capable as the best researchers, in many cases. Thus, the information that they produce should be trusted.

Geographical Citizen Science as Participatory Science

Against the technical, social and cultural background of citizen science, we offer a framework that classifies the level of participation and engagement of participants in citizen science activity. While there is some similarity between Arnstein’s (1969) ‘ladder of participation’ and this framework, there is also a significant difference. The main thrust in creating a spectrum of participation is to highlight the power relationships that exist within social processes such as urban planning or in participatory GIS use in decision making (Sieber 2006). In citizen science, the relationship exists in the form of the gap between professional scientists and the wider public. This is especially true in environmental decision making where there are major gaps between the public’s and the scientists’ perceptions of each other (Irwin 1995).

In the case of citizen science, the relationships are more complex, as many of the participants respect and appreciate the knowledge of the professional scientists who are leading the project and can explain how a specific piece of work fits within the wider scientific body of work. At the same time, as volunteers build their own knowledge through engagement in the project, using the resources that are available on the Web and through the specific project to improve their own understanding, they are more likely to suggest questions and move up the ladder of participation. In some cases, the participants would want to volunteer in a passive way, as is the case with volunteered computing, without full understanding of the project as a way to engage and contribute to a scientific study. An example of this is the many thousands of people who volunteered to the Climateprediction.net project, where their computers were used to run global climate models. Many would like to feel that they are engaged in one of the major scientific issues of the day, but would not necessarily want to fully understand the science behind it.

Therefore, unlike Arnstein’s ladder, there shouldn’t be a strong value judgement on the position that a specific project takes. At the same time, there are likely benefits in terms of participants’ engagement and involvement in the project to try to move to the highest level that is suitable for the specific project. Thus, we should see this framework as a typology that focuses on the level of participation (Figure 2).

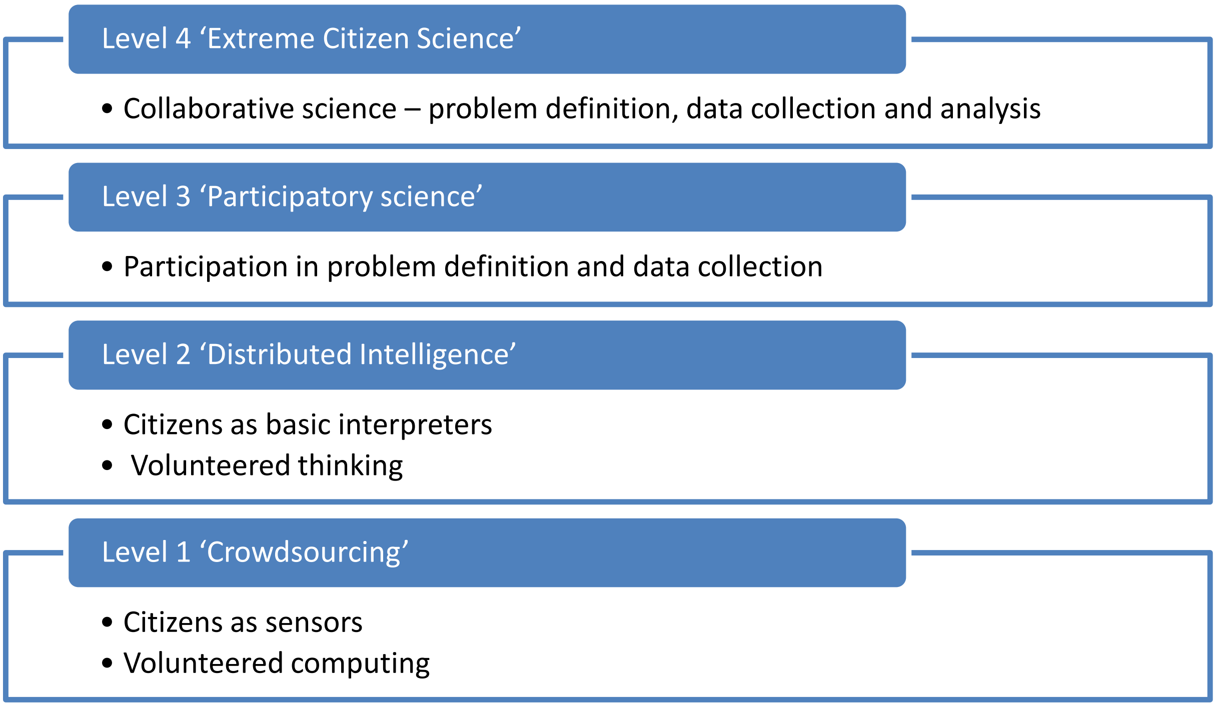

Figure 2 – Levels of participation and engagement in Citizen Science projects

At the most basic level, participation is limited to the provision of resources, and the cognitive engagement is minimal. Volunteered computing relies on many participants that are engaged at this level and, following Howe (2006), this can be termed 'crowdsourcing'. In participatory sensing, the implementation of a similar level of engagement will have participants asked to carry sensors around and bring them back to the experiment organiser. The advantage of this approach, from the perspective of scientific framing, is that, as long as the characteristics of the instrumentation are known (e.g. the accuracy of a GPS receiver), the experiment is controlled to some extent, and some assumptions about the quality of the information can be used. At the same time, running projects at the crowdsourcing level means that, despite the willingness of the participants to engage with a scientific project, their most valuable input – their cognitive ability – is wasted.

The second level is 'distributed intelligence' in which the cognitive ability of the participants is the resource that is being used. Galaxy Zoo and many of the 'classic' citizen science projects are working at this level. The participants are asked to take some basic training, and then collect data or carry out a simple interpretation activity. Usually, the training activity includes a test that provides the scientists with an indication of the quality of the work that the participant can carry out. With this type of engagement, there is a need to be aware of questions that volunteers will raise while working on the project and how to support their learning beyond the initial training.

The next level, which is especially relevant in 'community science' is a level of participation in which the problem definition is set by the participants, and in consultation with scientists and experts, a data collection method is devised. The participants are then engaged in data collection, but require the assistance of the experts in analysing and interpreting the results. This method is common in environmental justice cases, and goes towards Irwin's (1995) call to have science that matches the needs of citizens. However, participatory science can occur in other types of projects and activities – especially when considering the volunteers who become experts in the data collection and analysis through their engagement. In such cases, the participants can suggest new research questions that can be explored with the data they have collected. The participants are not involved in detailed analysis of the results of their effort – perhaps because of the level of knowledge that is required to infer scientific conclusions from the data.

Finally, collaborative science is a completely integrated activity, as it is in parts of astronomy where professional and non-professional scientists are involved in deciding on which scientific problems to work and the nature of the data collection so it is valid and answers the needs of scientific protocols while matching the motivations and interests of the participants. The participants can choose their level of engagement and can be potentially involved in the analysis and publication or utilisation of results. This form of citizen science can be termed 'extreme citizen science' and requires the scientists to act as facilitators, in addition to their role as experts. This mode of science also opens the possibility of citizen science without professional scientists, in which the whole process is carried out by the participants to achieve a specific goal.

This typology of participation can be used across the range of citizen science activities, and one project should not be classified only in one category. For example, in volunteer computing projects most of the participants will be at the bottom level, while participants that become committed to the project might move to the second level and assist other volunteers when they encounter technical problems. Highly committed participants might move to a higher level and communicate with the scientist who coordinates the project to discuss the results of the analysis and suggest new research directions.

This typology exposes how citizen science integrates and challenges the way in which science discovers and produces knowledge. Questions about the way in which knowledge is produced and truths are discovered are part of the epistemology of science. As noted above, throughout the 20th century, as science became more specialised, it also became professionalised. While certain people were employed as scientists in government, industry and research institutes, the rest of the population – even if they graduated from a top university with top marks in a scientific discipline – were not regarded as scientists or as participants in the scientific endeavour unless they were employed professionally to do so. In rare cases, and following the tradition of 'gentlemen/women scientists', wealthy individuals could participate in this work by becoming an 'honorary fellow', or affiliated to a research institute that, inherently, brought them into the fold. This separation of 'scientists' and 'public' was justified by the need to access specialist equipment, knowledge and other privileges such as a well-stocked library. It might be the case that the need to maintain this separation is a third reason that practising scientists shy away from explicitly mentioning the contribution of citizen scientists to their work in addition to those identified by Silvertown (2009).

However, similarly to other knowledge professionals who operate in the public sphere, such as medical experts or journalists, scientists need to adjust to a new environment that is fostered by the Web. Recent changes in communication technologies, combined with the increased availability of open access information and the factors that were noted above, mean that processes of knowledge production and dissemination are opening up in many areas of social and cultural activities (Shirky

2008). Therefore, some of the elitist aspects of scientific practice are being challenged by citizen science, such as the notion that only dedicated, full-time researchers can produce scientific knowledge. For example, surely, it should be professional scientists who can solve complex scientific problems such as long-standing protein-structure prediction of viruses. Yet, this exact problem was recently solved through a collaboration of scientists working with amateurs who were playing the computer game Foldit (Khatib et al. 2011). Another aspect of the elitist view of science can be witnessed in interaction between scientists and the public, where the assumption is of unidirectional 'transfer of knowledge' from the expert to lay people. Of course, as in the other areas mentioned above, it is a grave mistake to argue that experts are unnecessary and can be replaced by amateurs, as Keen (2007) eloquently argued. Nor is it suggested that because of citizen science, the need for professionalised science will diminish, as, in many citizen science projects, it seems that the participants accept the difference in knowledge and expertise of the scientists who are involved in these projects (Bonney et al. 2009). At the same time, the scientists need to develop respect towards those who help them beyond the realisation that they provide free labour, which was noted above.

Given this tension, the participation hierarchy can be seen to be moving from a 'business as usual' scientific epistemology at the bottom, to a more egalitarian approach to scientific knowledge production at the top. The bottom level, where the participants are contributing resources without cognitive engagement, keeps the hierarchical division of scientists and the public. The public is volunteering its time or resources to help scientists while the scientists explain the work that is to be done but without expectation that any participant will contribute intellectually to the project. Arguably, even at this level, the scientists will be challenged by questions and suggestions from the participants, and if they do not respond to them in a sensitive manner, they will risk alienating participants. Intermediaries such as the IBM World Community Grid, where a dedicated team is in touch with scientists who want to run projects and a community of volunteered computing providers, are cases of 'outsourcing' the community management and thus allowing, to an extent, the maintenance of the separation of scientists and the public.

As we move up the ladder to a higher level of participation, the need for direct engagement between the scientist and the public increases. At the highest level, the participants are assumed to be on equal footing with the scientists in terms of scientific knowledge production. This requires a different epistemological understanding of the process, in which it is accepted that the production of scientific insights is open to any participant while maintaining scientific standards and practices such as systematic observations or rigorous statistical analysis to verify that the results are significant. The belief that, given suitable tools, many lay people are capable of such endeavours is challenging to some scientists who view their skills as unique. As the case of the computer game that helped in the discovery of new protein formations (Khatib et al. 2011) demonstrated, such collaboration can be fruitful even in cutting-edge areas of science. However, it can be expected that the more mundane and applied areas of science will lend themselves more easily to the fuller sense of collaborative science in which participants and scientists identify problems and develop solutions together. This is because the level of knowledge required in cutting-edge areas of science is so demanding.

Another aspect in which the 'extreme' level challenges scientific culture is that it requires scientists to become citizen scientists in the sense that Irwin (1995), Wilsdon, Wynne and Stilgoe (2005) and Stilgoe (2009) advocated. In this interpretation of the phrase, the emphasis is not on the citizen as a scientist, but on the scientist as a citizen. It requires the scientists to engage with the social and ethical aspects of their work at a very deep level. Stilgoe (2009, p.7) suggested that, in some cases, it will not be possible to draw the line between the professional scientific activities, the responsibilities towards society and a fuller consideration of how a scientific project integrates with wider ethical and societal concerns. However, as all these authors noted, this way of conceptualising and practising science is not widely accepted in the current culture of science.

Therefore, we can conclude that this form of participatory and collaborative science will be challenging in many areas of science. This will not be because of technical or intellectual difficulties but mostly because of the cultural aspects that were mentioned throughout this chapter. This might end up being the most important outcome of citizen science as a whole, as it might eventually catalyse the education of scientists to engage more fully with society.

Conclusions

Geographical citizen science has clearly grown in recent years and is showing significant potential in areas such as biodiversity, air pollution or recording the changing shapes of cities. There are, however, two issues that are critical when considering the research directions that link VGI, participatory GIS and citizen science.

First and foremost, there is a need to consider which scientific questions can be answered by citizen science according to the patterns of data collection, the ability to recruit and train volunteers, the suitable participation level, and other aspects of VGI. Second, there is a need to overcome the cultural issues and to develop an understanding and acceptance of citizen science within the scientific community. This will require challenging some of the deeply held views in science, such as viewing uncertainty not as something that can be eliminated through tighter protocols but as an integral part of any data collection, and therefore developing appropriate methods to deal with it during analysis. Moreover, the view of science as separate from societal and ethical concerns is also a challenge – especially at higher levels of engagement between scientists and participants.

One intriguing possibility is that citizen science will work as an integral part of participatory science in which the whole scientific process is performed in collaboration with the wider public. Some examples are already emerging in geography (Pain 2004) and might provide direction for the future development of citizen science projects.

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