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Citizen science technologies and new opportunities for participation

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Highlights

- New technologies supporting data collection, data processing and visualisation, and the communication of ideas and results create a wide range of opportunities for participation in citizen science.
- Technologies are especially beneficial for opening additional channels for public involvement in research, allowing participants to contribute through a range of activities and engaging newer audiences.
- There is a range of existing resources to help project co-ordinators develop and maintain citizen science technologies.
- It is important to consider issues such as participant demographics, affordability and access, and fitness for purpose when selecting technologies.

Introduction

In the latter part of the nineteenth century, there was a paradigm shift with the institutionalisation of scientific activities through the establishment of research institutions and a growing emphasis on rigour, processes and protocols (see also Mahr et al. in this volume). Members of the public remained contributors to scientific research throughout this process, albeit in selected areas of study including astronomy, archaeology, ecology and the natural sciences. During this time, researchers primarily involved citizen science volunteers in data collection initiatives, with observations interpreted and analysed by professional scientists (e.g., the Audubon Christmas Bird Count). Such data collection generally followed a paper-based approach, with volunteers either systematically recording observations or individually sending evidence such as photographs or specimens to professional scientists, along with key metadata such as observation time and location (Miller-Rushing, Primack & Bonney 2012).

The recent proliferation of Information and Communication Technologies (ICT) such as mobile technology, the rise of Web 2.0 (e.g., moving beyond static web pages towards user-generated content and social media) and the ubiquity of high-speed internet has resulted in a further paradigm shift, this time in citizen science (Silvertown 2009). The rising interest in, and popularisation of, science and technology, as well as the push by governments and institutions for Science, Technology, Engineering and Math (STEM) education, have further created an excellent environment for individuals and communities to participate in scientific research (see Haklay in this volume). Participation itself now takes numerous forms extending far beyond data collection, such that the very conceptualisation of a citizen science project can now be initiated by individuals and their communities rather than scientists (see Ballard et al.; Novak et al., both in this volume).

This chapter discusses the new tools and technologies that have influenced citizen science and, as a result, revolutionised how citizens and communities can participate and engage in research. The following section presents a high-level overview of the various tools and technologies used in citizen science as well as resources to allow projects to develop similar tools and technologies. This is followed by a discussion of how key technological developments have created and expanded opportunities for citizen participation. The chapter concludes with key policy implications, as well as a brief discussion of how the future of citizen science may be shaped by, and benefit from, emerging technologies and online services.

Overview of citizen science technologies

New technologies facilitate scientific research by supporting the collaborative collection of data and dissemination of information in real-time (Mooney, Corcoran & Ciepluch 2013). These platforms also support social interactions and organisation between public participants and scientific researchers, and among public participants and their communities. As such, citizen participation in democracy is now transitioning from one-way broadcasts to two-way dialogues, empowering more people to express their voices and drive change. This is also true in the context of scientific research.

Citizen science participation in data collection can be explicit (when citizens collect the data themselves) or implicit (when contributors share geolocated photographs, videos or messages on social media). Explicit data collection can now be carried out through a wide range of new instruments, devices, tools (including do-it-yourself, or DIY, technologies) and mobile apps that can be easily built, bought or borrowed by citizens, communities and enthusiasts. However, the use of ICT does not always guarantee high data quality and participant engagement.

On the contrary, adopting suboptimal ICT can hurt projects through hidden costs including poor usability and lack of appropriate functionality (Wiggins 2013). Different mechanisms for data collection should usually be considered, based on user preferences, demographics and constraints (see box 21.1). For example, participants less familiar with technologies like mobile apps may prefer to provide data via more traditional forms such as pen-and-paper-based data sheets. Facilitating participation through a range of channels can help avoid age-dependent bias, as well as biases that may exclude low resource communities.

Researchers have identified several technologies that are promising for the field of citizen science, including wireless sensor networks, online gaming (Magnussen 2017) and, perhaps most importantly, the development and adoption of smartphones and mobile applications (Newman et al. 2012). Technology development has steered the direction of citizen science and offered new mechanisms for engaging volunteers. While some projects build their own tools and technologies, there are a number of resources to help projects recruit and communicate with volunteers, collect, share, store and manage data, and enhance participation (table 21.1).

Project websites

Most citizen science projects have a presence on the web to (1) provide information, (2) recruit and (3) manage volunteers, and (4) allow citizens to contribute to research by collecting or analysing data. Initiatives like Project BudBurst (Johnson 2016), where volunteers provide information on plant phenology cycles, employ websites with information and basic

Table 21.1 Different types of technologies and supporting resources used in citizen science

	Supporting resources	Purpose
General purpose technologies		
Project websites	Development frameworks.	Make it easier for users to build websites.
Project catalogues	Existing catalogues and directories of citizen science projects.	Allow users to list projects and/or conduct research.
Web 2.0 and social media	Most social media platforms use application programming interfaces (APIs) to make it easier to create posts and access data. Third-party tools like TweetDeck and Hootsuite allow posts on multiple accounts/platforms.	Help users collect data from, or through, social media sites and communicate with volunteers.
Technologies to support data collection and analysis		
Mobile websites and apps	Tools to support responsive design and hybrid apps.	Make it easier for projects to develop websites that are accessible on mobile devices or tablets.
Smartwatches and wearables	Development kits.	Help users automatically collect data as they go about their everyday activities.
DIY sensors and the Internet of Things (IoT)	DIY sensor kits.	Help users build sensors for large-scale, ongoing data collection.
Drones	Drone kits.	Help users collect data in difficult to reach environments.
Data analysis tools	Platforms that process, visualise and export data.	Help users answer research questions by analysing data and detecting trends.
Mapping technologies	Mapping platforms.	Allow projects to publish data on maps and integrate various data layers to support analysis.

Table 21.1 (continued)

	Supporting resources	Purpose
Improving the citizen science experience		
Virtual reality and augmented reality	Virtual reality headsets.	Create an immersive experience to augment or replace real world environments.
Open data and supporting resources	Data standards; data storage and management platforms.	Collect, store, and manage open and interoperable data in a publicly accessible repository, enabling access and use beyond the lifetime of a particular project.

forms for data collection. Test My Brain, for example, provides more visual approaches to data analysis, such as by allowing volunteers to sift through images to perform tasks such as counting craters or matching or classifying images. The websites of virtual citizen science projects like EyeWire (Kim et al. 2014) also employ real-time communication such as chat systems or forums to help participants and create a more supportive community.

While websites broadly facilitate participation for users, the increasing availability of *development frameworks* support and empower project leaders. Development frameworks help project owners create websites and other tools to support citizen science projects without the need to write complex software from scratch. At the most basic level, WordPress, Django, Wix and Weebly are examples of frameworks that provide means for interacting with participants through features like content management, authoring (a content authoring feature is used to create multimedia content typically for delivery on the World Wide Web), authentication, blogging and basic input via forms. Such frameworks also support responsive design to deliver content appropriate for display on mobiles, desktops and tablets. For more advanced users, frameworks such as PhoneGap and Ionic help developers write websites in HTML and JavaScript, which can be easily packaged as mobile applications. Ushahidi, Inc. and Open Data Kit (ODK) provide a way to easily develop customised surveys and set up websites and mobile applications that can be distributed to crowdsource information. These frameworks also allow project owners to aggregate, visualise and analyse the data collected.

Development frameworks simplify the web development process. However, it is important to ensure that project websites are appropriately designed for their target users. Although customising templates supported by web hosting platforms is an apparently inexpensive solution, it often comes with hidden costs such as poor usability and awkward workflows (Wiggins 2013). Newman and colleagues (2010) explored the various factors that should be considered when developing websites for citizen science that are particularly relevant to websites that involve interactive maps.

Project catalogues

Websites like SciStarter, The Federal Catalogue of Crowdsourcing and Citizen Science, iNaturalist, Natusfera, Citsci.org and Zooniverse serve as project catalogues, or online directories that benefit citizen science by helping participants find projects to contribute to and collecting information for researchers to analyse. Many of these platforms also support participation directly. For example, iNaturalist and Natusfera allow citizen science volunteers to find biodiversity monitoring projects and directly upload biodiversity data. Some platforms, like Citsci.org, allow participants to create their own citizen science projects to initiate data collection and analysis via websites and/or mobile applications. Other platforms, most notably Zooniverse, provide cyberinfrastructure supporting data analysis via tasks such as classification, annotation and tagging (in a variety of fields such as arts, biology, literature and planetary science). Unlike development frameworks, which were designed for use in any context, these project catalogues are designed specifically to support citizen science.

Web 2.0 and social media

Web 2.0 and social media offer new means for citizens to express themselves and connect with others via open and free platforms. Citizen science has benefitted from social media platforms like Twitter, Facebook and Instagram that help project co-ordinators recruit and communicate with participants. In addition, data generated from online platforms such as Twitter can be automatically processed and analysed to provide citizen-generated data on critical events and emergencies (Gao, Barbier & Goolsby 2011; Shaw, Surry & Green 2015). The very nature of social media has also paved the way for global communities to self-organise, develop and become more sustainable, helping promote grassroots or bottom-up citizen science activities (see also Hecker et al. in this volume).

Mobile websites and apps

Technological developments in smartphones are revolutionising citizen science: Web-based data capture, analysis and presentation tools and apps are in common use, and a wide range of next-generation environmental sensors to be coupled to smartphones are under development. From online recording and real-time mapping to digital photography, there are tools for most tasks (Tweddle et al. 2012). In terms of actually making the record, many field recorders still use pencil and notebook or record cards (although increasingly relying on GPS handsets for geolocation) and this may be the most efficient method for capturing data in the field for many experts. However, communications technology has facilitated the ability to make records, especially incidental records, through smartphone apps. Currently, there are apps linking directly to iRecord (for efficient data flow) for recording ladybirds, butterflies, orthopterans, mammals and invasive non-native species. These provide the ability to take a photograph (or potentially, for species such as orthopterans to make a sound recording), capture location via GPS and store the record for later upload to iRecord. These apps are an ideal tool for widening participation, especially when observing species that are relatively large or immobile, conspicuous and easy to identify. Records still need to be verified for them to become scientifically useful though, and one important advantage of interoperable data systems is that there is the potential to bring together records from many different websites and smartphone apps to facilitate efficient verification (Pocock et al. 2015).

A collection of recommendations specific for citizen science that provides support and advice for planning, design and data management of mobile apps and platforms that will assist learning from best practice and successful implementations can be found in Sturm et al. (2017). Smartphones support many of the same data collection functions as desktop computers, allowing volunteers to provide observations and opinions through web forms and supporting simple data analysis tasks. More complex tasks are harder to support through mobile apps or mobile websites so some projects are not accessible via mobile devices (e.g., EyeWire). However, the ability to deliver content via mobile phones and tablets provides an excellent opportunity for citizen science projects to involve participants at all times, even while they travel. Further, mobile devices may facilitate

Fig. 21.1 The Project BudBurst website is designed to recruit and train participants, collect and publish data and provide education materials. The project also supports a mobile application mainly designed to facilitate data collection. The app is coded in HTML5, which is easier to develop and maintain but has less functionality than a native app available for Android or iPhone.

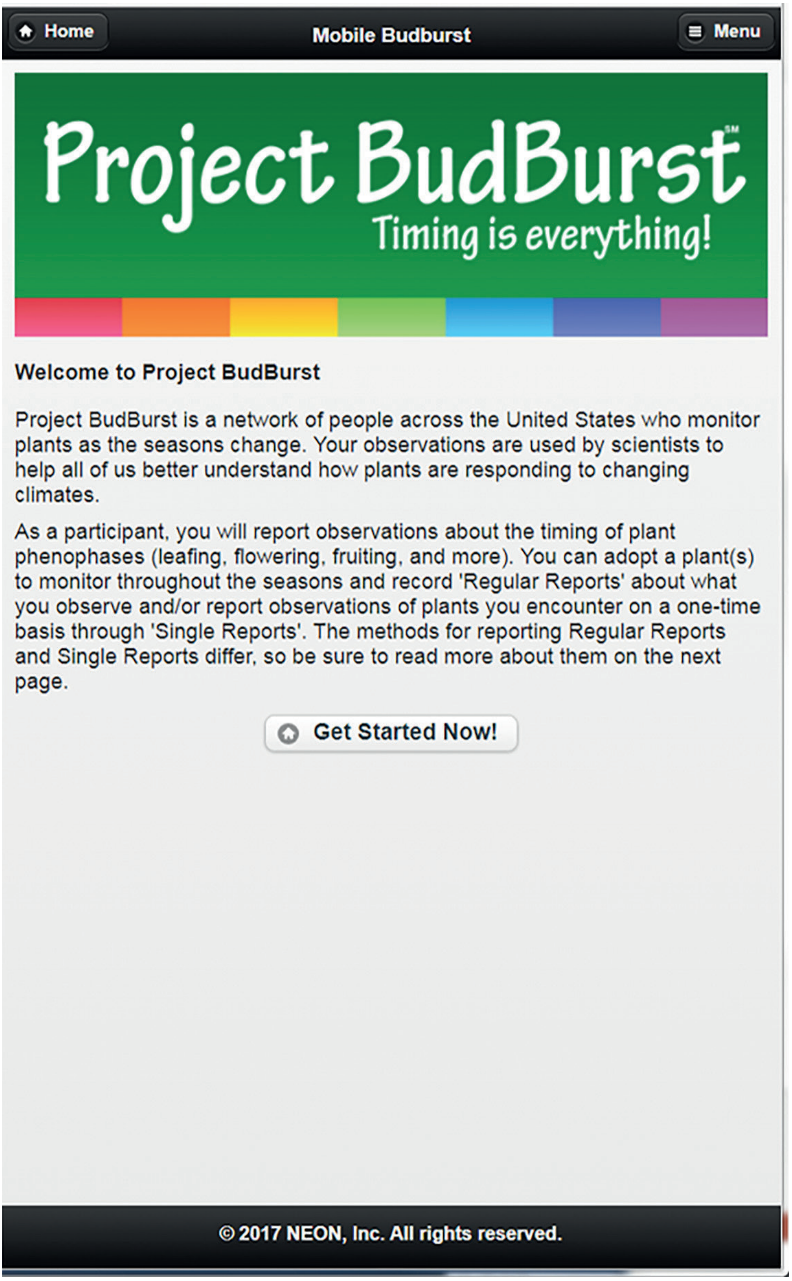

Fig. 21.1 (continued)

access by larger, more diverse populations – access to the internet via mobile and tablet exceeded desktop for the first time in November 2016 (Gibbs 2016). Many citizen science projects therefore support both web-based and mobile participation. Project BudBurst hosts a website for desktop users, as well as an HTML5 website for mobile users (figure 21.1) (HTML5 is a markup language used for structuring and presenting content on the World Wide Web), and has explored an additional gamified app (Bowser et al. 2013). The iRecord Dragonflies mobile web application is another example of this approach.

Responsive design enables websites to be viewed according to the device being used to access them, by adapting layouts, media items and other content to different resolutions and screen-sizes. For projects that seek to host a website and a mobile site or app, styling tools employing responsive design, including Bootstrap and Boilerplate, can greatly simplify this process. Alternately, *hybrid apps* are web pages packaged into mobile apps that can run on multiple operating systems without the need for a web browser. The process of developing hybrid apps too can be greatly simplified by using frameworks such as Ionic, PhoneGap and Cordova. Finally, *native apps* are apps that are developed individually for different mobile operating systems using different programming languages. Native apps require greater investment and development effort but support a more interactive experience, and enable developers to use the phone's hardware to a greater extent.

Smartwatches and wearables

The increasing development of wearables and smartwatches offers the opportunity to explore new forms of engagement and data collection (e.g., Tse & Pau 2016; Nieuwenhuijsen et al. 2015). Smartwatches or wearables can provide information on the environment, human health and mobility using a wide range of sensors such as accelerometers, GPS, cameras, microphones, heart rate sensors, barometers, compasses and air quality sensors. Smartphones, smartwatches and wearables also facilitate lifelogging, recording activities throughout the day to help people understand how their habits and routines relate to external variables such as environmental conditions. For example, AirBeam provides wearable sensors and the AirCasting Android app for collecting air quality information as citizens travel around cities.

Do-it-yourself sensors and the Internet of Things

Do-it-yourself technologies have recently become popular, mainly due to the development of makerspaces or hackerspaces (see box 21.2; see also Novak et al. in this volume). These collaborative spaces offer different tools and facilities, including equipment such as 3-D printers, laser cutters and computer-controlled machines, for making, learning, exploring and sharing technologies. Open to a diverse community (from kids to budding entrepreneurs), makerspaces seek to provide hands-on learning, support community interests and creative expression, and foster critical thinking, particularly linked to STEM education. Makerspaces are also used as incubators and accelerators for business start-ups. In addition to persistent spaces like Fab Labs, participatory technology development is also supported through events like hackathons (see box 21.2; see also Gold & Ochu in this volume).

While traditional sensors are developed by engineers and experts, citizens and enthusiasts can now make use of DIY devices such as Arduino and Raspberry Pi. These are essentially basic computers to which different sensor modules can be attached. A large variety of modules can be used, including GPS sensors, accelerometers and cameras. Projects such as Smart Citizen (Diez & Posada 2013) use DIY sensors to help participants upload environmental data for analysis. Another example is the Cosmic Pi project, which aims to use low-cost, pocket-size detectors to detect cosmic rays.

Drones

Unmanned aerial vehicles (UAVs), or 'drones', are powerful platforms for monitoring and reporting, especially in terrains that are difficult to access on foot. In some areas, drones have a bad reputation because of their role in military missions (for surveillance or bombing) and due to privacy concerns. However, drones and other DIY aerial platforms can be used for social good (Choi-Fitzpatrick 2014). For example, members of Digital Democracy worked in Guyana with the local Wapishana people to build DIY drones to monitor and map deforestation (MacLennan 2014).

The 2010 Deepwater Horizon oil spill in the Gulf of Mexico illustrates the complex nature of aerial data collection by citizen science communities, since BP (the company responsible of the spill) and the US government explicitly denied monitoring access to journalists, citizen groups and scientists. While the word 'drones' typically evokes a high-technology approach, this is not always the case. In the Public Labs model, aerial mapping based on DIY balloon and kite systems serves as a powerful alternative strategy to monitor the environment (Dosemagen, Warren & Wylie 2011).

Data visualisation tools

Data visualisation is helpful for feeding analysed data back to participants and for presenting results to policymakers. There is a range of tools available to support project co-ordinators and volunteers in processing, analysing and visualising data; and many also come with plug-ins or modules to provide further analytic capabilities (see also Williams et al. in this volume). Earthwatch's Freshwater Links and UCL's Extreme Citizen Science: Analysis and Visualisation (ECSAnVis) are examples where users can visualise data coming from a variety of remote databases. Simple tools like Google Charts (an interactive web service that creates graphical charts from user-supplied information) also provide a quick means of visualising data online as configurable charts and graphs. As mentioned earlier, more complex frameworks such as Ushahidi, Inc. and ODK support both data collection and data analysis/visualisation.

Mapping technologies

Spatial data analysis is often critical to understanding variables ranging from biodiversity presence and distribution, to local environmental conditions, human population and transportation patterns. Many websites and most citizen science apps provide feedback to participants through maps, using map layers to add collected information as point data (e.g., iNaturalist displays points for observations of different species) and to overlay information such as heat maps (e.g., the Environment Hamilton's INHALE Hamilton project presents air quality information in this way) or geometries (e.g., Safecast presents levels of radiation and air quality data in this way, among others).

GIS tools have a long history of expert use, but mapping technologies have only recently been made easily available to non-expert users. Tools like Google Maps and OpenStreetMap paved the way for location services such as routing, searching, trip planning, traffic estimation and other routine tasks now used on a daily basis. Overlays can be created fairly easily using the methods made available in standard mapping tools such as OpenStreetMap, Google Maps, OpenLayers and Mapbox. Currently, the largest citizen science mapping initiative is Google Local Guides, with 50 million volunteers in October 2017.

Virtual reality and augmented reality

Virtual reality and augmented reality may be viable and cost-effective ways to improve data collection – for example, measuring the colour of the sea in the Citclops project (Wernand et al. 2012), train citizen science volunteers with personalised and immediate feedback, track individual data quality and improve retention and motivation, for example, increasing patient engagement in rehabilitation exercises using computer-based citizen science (Laut et al. 2015).

The availability of smartphones has resulted in investigations into how augmented reality can be embedded into standard interfaces – for example, overlaying objects on top of on-screen displays of camera views or base map layers. In addition to employing gamification approaches, which use the motivational elements of games to engage users, virtual or augmented reality can provide engaging applications to support citizen science through the increased recruitment of volunteers. And virtual reality can improve data quality and participant engagement by allowing users to dynamically interact in immersive environments (Klemmer, Hartmann & Takayama 2006).

Open data and supporting resources

Open data are both a resource for citizen science and an output of most citizen science initiatives. Open data policies implemented by governments, businesses and universities have begun to make large volumes of data available, which is openly accessible for the public to query, process and analyse. Many citizen science projects also make their data available as downloadable raw-data files, queryable databases or processed visualisations. Technical developments supporting open data include data standards, which promote interoperable data collection and sharing (Williams et al. in this volume) and are developed and maintained by organisations like the Open Geospatial Consortium (OGC). Expanded data storage, such as scalable databases and cloud storage, also supports open data, with computational, storage and hosting resources available from providers either for free (e.g., WordPress and Google Sites as general technologies; CitSci.org for citizen science) or on-demand (e.g., Amazon Web Services), offering much needed help for citizen science projects.

Box 21.1. Collaborative research on sustainable fish stocking in Germany

Angling clubs are fishing rights holders in Germany, and any changes to the governance and management of fisheries depends in part on decisions made by these clubs. Fish stocking is the practice of raising fish in a hatchery and releasing them into a river, lake or the ocean to supplement existing populations, or to create a population where none exists. Stocking may be done for the benefit of commercial, recreational or tribal fishing, but may also be done to restore or increase a population of threatened or endangered fish in a body of water closed to fishing. Stocking is a contested issue, whose success or failure depends on a range of social, ecological and evolutionary factors (Arlinghaus et al. 2014). To learn about successful and unsuccessful stocking practices, as well as associated genetic and other ecological risks, researchers partnered with 18 angling clubs in Lower Saxony on a transdisciplinary research project called Besatzfisch (which translates as 'stocked fish').

Working in close collaboration with the angling clubs, the research team developed an experiment involving radical stocking density treatments of northern pike (*Esox lucius* L.) and common carp (*Cyprinus carpio* L.) in angler-managed flooded gravel pits. Workshops were used to develop specific goals, objectives and hypotheses and to allocate treatment to 24 angler-managed flooded gravel pits. Outcomes were monitored jointly through a series of workshops, creating opportunities for reflexive learning.

Anglers participated in fish surveys and completed angling diaries to monitor carp. The research team chose paper-and-pencil-based diaries to allow anglers of all age groups to participate. Surveys of club anglers were also used to understand attitudes, norms and other human dimensions related to stocking and to behaviours (Arlinghaus et al. 2014; Gray et al. 2015; Fujitani et al. 2016). Results showed that the integration of anglers into the experiments was instrumental in improving ecological knowledge.

This project shows how citizen science using paper-and-pencil-based diaries, workshops and flooded gravel pits can support the co-production of knowledge. Given the age of many club anglers, it is likely that an app would reduce participation and bias the study towards the younger demographic segment. The benefits of ICT-enabled versus non-ICT-enabled citizen science approaches should therefore be carefully weighed depending on the target audience and project goals.

Box 21.2. Participatory technology development

Making and hacking democratise the creation of the hardware and software that aid in research, just as citizen science democratises the scientific research process itself. Fab Lab and TechShop are names used for two particular types of makerspaces:

> The *fabrication laboratories* (Fab Labs)[1] programme was initiated in 2001 by Professor Neil Gershenfeld of the Massachusetts Institute of Technology (MIT) and it has since become a collaborative and global network. Fab Labs are currently governed by the Fab Foundation, which lists more than 1,000 Fab Labs from all over the world (including 700 in Eurasia, 300 in America, 40 in Africa and 8 in Oceania; Gershenfeld 2008).
>
> *TechShop* was a chain of makerspaces started in 2006 in California. It was supported by monthly fees from members, which supported access to machines and tools. TechShop defined makerspaces as part prototyping and fabrication studios and part learning centres. As of 2017 there were 10 locations in the United States: three in California, one in Arizona, one in Arlington, Virginia (near DC), one in Michigan, one in Texas, one in Pittsburgh, Pennsylvania, and one in Brooklyn, New York, as well as four international locations. On November 15, 2017, with no formal warning, the company closed and announced they would declare bankruptcy under Chapter 7 of the United States bankruptcy code (immediate liquidation).

Hackathons also have promoted the development of new technological products to facilitate citizen participation. Hackathons are short-term, collaborative design events where volunteers, often including computer programmers, engineers and designers, create new technologies for a prize or other reward. These new technologies are usually software projects and applications, but they can include hardware products as well. Hackathons may be sponsored and organised by companies, educational institutes, non-profit organisations or government agencies. The US National Aeronautics and Space Agency (NASA), for example, routinely hosts the International Space Apps Challenge, a 48-hour event where teams use public data to solve challenges in hardware, software, citizen science and information visualisation (Bowser & Shanley 2013).

Practical and policy considerations

This chapter has explored a wide range of technologies used in citizen science, and offered examples of existing resources available to researchers and project co-ordinators, ranging from web development frameworks to virtual reality headsets. The majority of these resources were not developed specifically for use in citizen science. Therefore, it is important to understand how these resources are being used in a citizen science context, as well as to assess their strengths and limitations for different citizen science contexts.

To complement their existing database of citizen science projects, SciStarter is compiling a database of tools and technologies that citizen science volunteers can build, borrow or buy. This database will help project co-ordinators and volunteers to:

- Find information about different tools and technologies, and determine which are suited to their needs;
- Access new tools and technologies by linking to blueprints, lending libraries and online marketplaces; and
- Identify gaps in existing hardware and infrastructure, which could be filled by new collaborations between the citizen science and maker movements, bringing two participatory paradigms into closer alignment.

Another opportunity lies in the collection and development of relevant data and metadata standards to promote the collection, sharing and use of interoperable citizen science data. This could include standards for citizen science observations that follow the structure of a common model, such as the ISO 19156 model for Observations and Measurement. A citizen science profile for this has been suggested in the Sensor Web Enablement for Citizen Science work within OGC (Williams et al. in this volume).

Citizen science tools and technologies also need to be maintained as well as developed. On the one hand, building new technology for use in a citizen science project offers extensive customisation and opportunities for collaborative or participatory design. However, on the other hand, these technologies must then be maintained by the core project team, rather than relying on external developers. It is also important to consider how and where technologies will be deployed. For example, sensors used in the WeSenseIt project[2] were installed in river banks, which are often difficult for citizens to access so professional help was required to maintain and service sensors (Mazumdar et al. 2016).

There are numerous policy considerations to the development or procurement and use of citizen science technologies. Data quality is a critical issue in citizen science, especially in policy contexts such as monitoring and regulation (see also Brenton in this volume; Williams et al. in this volume). It is important to consider fitness for purpose in all aspects of project design, including when designing or selecting citizen science technologies. For example, while some environmental monitoring sensors may align with regulatory standards, others may not (Volten et al. in this volume).

Funders and policymakers have both made it clear that citizen science activities should produce open and interoperable data. For example, recent guidance on crowdsourcing and citizen science issued by the Director of the US Office of Science and Technology Policy suggests that, 'federal agencies should design projects that generate datasets, code, applications and technologies that are transparent, open and available to the public, consistent with applicable intellectual property, security, and privacy protections' (Holdren 2015). Guidance in the EU tends to recommend a balanced approach to openness and emphasise interoperability. For example, in 2015 the European Commission's Horizon 2020 Framework Programme issued a call for the 'Coordination of Citizens' Observatories and Initiatives' (SC5-19-2017) seeking a team of researchers to help 'promote standards' and 'ensure interoperability'.

Some citizen science projects, particularly those run by government agencies, may be limited in the types of technologies they can use. The US Crowdsourcing and Citizen Science Act (15 U.S.C. § 3724 [2017]) tasks one government agency, the General Services Administration (GSA), with specifying the appropriate technologies and platforms to support citizen science activities. While these guidelines would strictly apply to all federal employees, citizen science projects hoping to influence government decision-making would be wise to consult any published list of GSA guidelines for citizen science technologies and tools. Additional policy guidance in the United States, the EU and elsewhere is likely to be issued as citizen science continues to grow.

Conclusions

As citizen science has evolved, new technologies have emerged to enable citizens and communities to contribute to citizen science in a variety of ways. The relevance, contribution and importance of technology in citizen science therefore demands much more attention from practitioners and communities. Mobile technologies will continue to revolutionise the field, an innovation particularly valuable for engaging new communities and stakeholders in citizen science, including younger populations and participants in developing countries. Technologies also support a wide range of project governance models. Many future citizen science endeavours will harness the power of social networking to larger effect in all aspects of research, with members of the public collaboratively conducting research, validating and publishing results. Resources that support technology development by making it easier to build websites, apps, sensors and maps similarly lower the barrier to entry for top-down and bottom-up models of citizen science alike. At the same time, the use of various technologies should be carefully considered, taking into account participant demographics, affordability and access, and fitness for purpose.

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Notes

1 https://www.fablabs.io/labs
2 http://www.wesenseit.com/