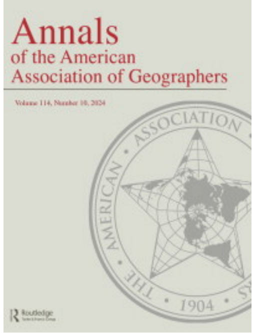


Annals of the American Association of Geographers

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/raag21

The Utilization of Maps in Geographic Citizen Science: A Preliminary Analysis of Usability and User Experience Issues and Opportunities

Artemis Skarlatidou, Marcos Moreu & Muki Haklay

To cite this article: Artemis Skarlatidou, Marcos Moreu & Muki Haklay (09 Dec 2024): The Utilization of Maps in Geographic Citizen Science: A Preliminary Analysis of Usability and User Experience Issues and Opportunities, Annals of the American Association of Geographers, DOI: 10.1080/24694452.2024.2426714

To link to this article: https://doi.org/10.1080/24694452.2024.2426714

ANNALS OF THE AMERICAN ASSOCIATION OF GEOGRAPHERS
https://doi.org/10.1080/24694452.2024.2426714

The Utilization of Maps in Geographic Citizen Science: A Preliminary Analysis of Usability and User Experience Issues and Opportunities

Artemis Skarlatidou, Marcos Moreu, and Muki Haklay

Department of Geography, University College London, UK

The rapid proliferation of geospatial technologies and the widespread utilization of Web and mobile maps by nonexpert audiences spurred new perspectives and research paradigms within geography. One area affected by this transformation is citizen science, where geospatial technologies facilitated its more widespread use and revolutionized the way scientific knowledge is coproduced, especially in the environmental context. Geographic citizen science is widely used to support the collection and analysis of geolocated scientific data, extend existing geographic data coverage, and enable communities to address local issues. The inherent complexity of geospatial interfaces and data is widely recognized and there is a wealth of geographic research focusing on improving human–map interactions, with less emphasis, nevertheless, given to citizen science. Not only do these applications have their unique characteristics, but inclusiveness is paramount, which further adds to these complexities. Through an investigation of 229 geographic citizen science applications, we provide an overview of how geographic interfaces are currently employed in citizen science. We then evaluate a selection of applications to identify critical usability barriers, which might have a detrimental impact on the overall user experience and the success of these projects. Among others, we found that geographic citizen science applications need to better support visual thinking and leverage participants' geographic knowledge. We subsequently provide a set of recommendations for map design and functionality and identify opportunities for future geovisualization research. *Key Words: citizen science, geovisualization, usability, user experience.*

The rapid proliferation of geospatial technologies, alongside the widespread adoption of Web and mobile maps used by a vast number of people connected to the Internet, has spurred new perspectives and research paradigms within geography. Neogeography (Turner 2006) and volunteered geographic information (Goodchild 2007) emerged in the mid-2000s, highlighting the transformative impact of new technologies in the production, consumption, and application of geographic information across diverse audiences. The blurring of professional and amateur knowledge production is not confined to geography alone, but it was experienced as a wider online phenomenon, known as crowdsourcing (Howe 2006). Crowdsourcing has had amongst others a tremendous impact on the way scientific knowledge is produced, giving rise to new imaginations of how science should be practiced (see, e.g., "Science 2.0" in Shneiderman 2008) and new conceptions of science–society interactions in a postnormal science context (Funtowicz and Ravetz 1993). Responsible research and innovation (RRI; Owen, Macnaghten, and Stilgoe 2012) and Open Science (Fecher and Friesike 2014) emerged in the late 2010s, primarily grounded in normative approaches of public participation in scientific research and an ethic of coproducing knowledge on equal terms, which have long been advocated by science, technology, and society (STS) scholars (Irwin 1995; Jasanoff 2003; Wynne 2006).

Citizen science—defined as "the scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Oxford English Dictionary 2014)—is playing a pivotal role in the transformation of scientific knowledge production

ARTICLE HISTORY
Initial submission, May 2024; revised submissions, August and September 2024; final acceptance, September 2024

CORRESPONDING AUTHOR Artemis Skarlatidou a.skarlatidou@ucl.ac.uk

and dissemination (for a more comprehensive analysis of citizen science definition challenges and project characteristics, the reader can refer to Haklay et al. 2021). Although citizen science is an old practice (Eitzel et al. 2017) its current utilization spans almost every scientific discipline, and it is further fueled by policy frameworks such as the European interpretation of Open Science (European Commission 2018), UN Sustainable Development Goals (UN 2015), UN Environment Programme (United Nations Environment Agancy 2017) and many state-based environmental policies. What is interesting is the growing public uptake and the way these opportunities are embraced, which Haklay (2021) attributed to several social trends (e.g., access to education, exposure to science, and wide use of digital technologies). For example, the Christmas Bird Count project, which has run since December 1900, involves participants who contribute more than 40 million bird observations annually (Audubon.org 2024). The Atlas of Living Australia (i.e., the portal to Australia's biodiversity data) reported in 2023 that 50 percent of its data (i.e., 115 million records) comes from citizen science (Roger, Slatyer, and Kellie 2023). Zooniverse, a citizen science hub primarily for natural sciences, has more than 2 million registered volunteers, but in a single week during the COVID-19 lockdown 200,000 participants contributed more than 5 million classifications, which is the equivalent of forty-eight years of research (Dinneen 2020). With numerous success stories, it comes as no surprise that the field is rapidly growing to not only support "data-hungry" disciplines with the collection of data at previously unprecedented spatiotemporal scales (Dickinson et al. 2012), but it is also used for advocacy purposes, local community action, and informing policymaking (Fraisl et al. 2022).

Many citizen science initiatives use geographic information technology to collect, process, visualize, and disseminate data. This growth of citizen science has brought into geography a "world-wide attention which would be unprecedented in the history of the discipline" (Trojan et al. 2019, 257). The term geographic citizen science (GCS) emerged to describe the intersection between volunteered geographic information (VGI) and citizen science. In examining this overlap, Haklay (2021) defined GCS as "the scientific work undertaken by members of the public where the data generated has an explicit geographic aspect" (15) and where the recording of spatial information is conducted in a systematic and objective way. Haklay (2021) further identified three broad themes in GCS: applications that use geographic information technology for the collection and analysis of geolocated scientific data (e.g., iNaturalist, Atlas of Living Australia); applications such as OpenStreetMap, which generate accurate and reliable geospatial information to extend existing geographic data coverage; and applications that enable participatory action research for addressing local issues and supporting communities or citizens' participation in policy and decision-making processes.

GCS has already had a massive impact in science and society (see, e.g., Skarlatidou and Haklay 2021). Yet the use of geographic interfaces and technologies by nonexpert user audiences means that "issues which have been central to geography are now part of the global consciousness, and many tools and data sets that were formerly used and examined only by geographers and other earth and environmental scientists, are now in the hands of the general public" (Trojan et al. 2019, 257). This brings new opportunities—for example, in terms of reimagining public participation to enable scientific knowledge production, social innovation, and social change—but it also creates a new set of implications. One of those is that the inherent complexity of geographic data and interfaces is frequently overlooked by citizen science practitioners, who do not have the knowledge and experience to design solutions that are easy to assemble, update, maintain, and use by scientists, policymakers, and members of the public. Simple and more complex geographic analyses require functionality that can be overwhelming to the average person with limited knowledge of geographic data collection and processing. Although citizen science scholarship has extensively discussed data quality and coverage issues, little attention has been paid to the cartographic design choices and their role in facilitating meaningful participation. Equally underexplored are issues of accessibility, usability, and the overall user experience provided by GCS applications, despite the fact that these are significant in terms of fostering inclusion, participant engagement, and retention and in terms of maximizing educational and social benefits for the people involved (Wald, Longo, and Dobell 2016; Skarlatidou, Hamilton, et al. 2019).

In this article we analyze SciStarter.org—one of the most popular citizen science hubs—to identify GCS applications and examine their general characteristics. Our aim is to provide an overview of how geospatial technologies are currently employed in citizen science, emphasizing their primary design and functionality components. We then use human–computer interaction (HCI) evaluation methods to reveal usability barriers and explore how these might impact the overall user experience. We connect our findings with the broader geographic literature emphasizing use and user issues of geovisualization and geospatial interfaces used by nonexpert audiences. This study aims to contribute equally to geographic and citizen science research that aims to advance our understanding of how interaction with geospatial interfaces can be improved to facilitate broader implementation of participatory approaches and contribute to democratizing the use and production of geographic information. Focusing on usability, this study aims to further enable more meaningful and inclusive contributions to GCS by individuals with diverse backgrounds, skills, and other characteristics. This is particularly crucial given the potential role of GCS in addressing some of the most pressing challenges our societies are facing, such as climate change, food and water insecurity, nuclear risks, and the unprecedented acceleration of species extinction.

Geographic Citizen Science: User Issues and Design Challenges

Citizen science primarily engages a demographic of well-educated participants mainly from the Global North, who nevertheless come from different cultural contexts and age groups and have different skills and motivations and various levels of experiences in terms of interacting with geospatial and digital technologies, as well as different goals and priorities (Skarlatidou and Haklay 2021). This diversity presents a significant design challenge for citizen science in terms of fostering and maintaining participation, achieving inclusivity, generating effective user experiences, successfully integrating user needs and expectations, creating user-friendly applications to ensure data quality, and so on (Preece 2016). Recently citizen science scholars started to pay even more attention toward including new audiences in the Global South, such as indigenous and marginalized communities in line with United Nations Leave No One Behind principle, which further adds to these complexities. These new audiences might include illiterate and nonliterate people, who have little to no experience interacting with digital technologies and maps, and who operate in contexts with very different sociotechnical characteristics and with limited technological infrastructure (for a thorough discussion of citizen science interaction challenges in the Global South see Pejovic and Skarlatidou 2020; Benyei et al. 2023). Recently, a growing number of studies reflect on such barriers and apply HCI methods and tools to make inclusion, usability, and accessibility higher strategic priorities. This slowly leads into a deeper understanding of how the design of citizen science applications can be improved to enhance user experience (Skarlatidou, Ponti, et al. 2019).

When citizen science applications incorporate geographic technologies the level of complexity is increased, due to the mapping component, and this influences how nonexperts (i.e., people without a cartographic or geographic background and skills) interact with these interfaces. This challenge has been highlighted in the map communication model in cartography since the 1950s. The distinction between expert and novice users and its implications for map development and use only began to receive attention in the second half of the twentieth century, however (Crampton 2001).

With the emergence of public Web mapping applications in the mid-2000s, elements of online human–map interaction drew the attention of geographers, emphasizing the importance of researching use and user issues. Understanding usability barriers and developing relevant standards, especially in the context of using online geospatial technologies in decision- and policymaking processes, became crucial. For example, participatory geographic information systems (PGIS) and critical geographic information systems (GIS) scholars have not only discussed power asymmetries (Corbett and Keller 2005; Sieber and Haklay 2015) but also the design of digital cartographic elements (e.g., map size, basic and more advanced interactivity options, color) to improve usability, usefulness, and the overall interaction in planning contexts (Haklay and Tobón 2003; Meng and Malczewski 2009; Skarlatidou, Cheng, and Haklay 2013; Butt and Li 2015; Atzmanstorfer et al. 2016). Similar studies have also taken place in the context of Web mapping applications supporting wayfinding tasks (see, e.g., Skarlatidou and Haklay 2006; Nivala, Brewster, and Sarjakoski 2008; Roth 2013) and in the design of VGI applications (Parker

2014). HCI methodological approaches and tools (e.g., user-centered design, usability engineering, user testing, eye tracking) have also been extensively used (Andrienko et al. 2002; Cöltekin et al. 2009) to develop accessibility, usability and trust guidelines (see, e.g., Nivala 2007; Skarlatidou et al. 2011; Hennig, Zobl, and Wasserburger 2017) and provide recommendations that aim to improve the overall user experience of nonexpert user audiences in terms of how they interact with online maps.

Although several of these findings are relevant to the context of GCS, unfortunately specific interaction barriers within GCS remain largely anecdotal. Not only there are different technological solutions that can now be used to deliver different types of GCS projects, but those who design and implement citizen science initiatives do not usually have the skills and knowledge to understand the different requirements that technological choices will impose to their projects (Antoniou and Potsiou 2021). The emphasis on coproduction of scientific knowledge through the creation of new spatial data sets and sophisticated geospatial analyses means that interaction barriers might not only influence the success of these projects in terms of enabling and sustaining participation, but could have a detrimental effect on data quality. For example, Newman et al. (2010) highlighted that "as more web mapping applications are developed, more attention must be given to their usability, user satisfaction, required tasks, data quality, and applicability related to each purpose and audience they are being built to support" (1853). The authors presented one of the first studies implementing an HCI approach in the development and evaluation of CitSci.org. Lamourex and Fast (2019) also evaluated the mapping component of different crowdsourcing applications (i.e., Ushahidi, Mapptionaire, Survey123, GIS Cloud, and Open Data Kit) for an ornithology citizen science project; however, the emphasis is on providing an overview of the functionalities they support and not on usability.

A recent attempt to delve deeper into how nonexperts interact with GCS can be found in *Geographic Citizen Science Design: No One Left Behind* (Skarlatidou and Haklay 2021). The book offers a collection of GCS case studies analyzed with the aim to uncover anecdotal evidence of nonexperts' interactions with GCS applications, both in the Global North (e.g., RinkWatch, Grasslander, Hush City, Global Forest Watch, Cyclist Geo-C app, and ImproveMyCity projects) and the Global South (e.g., using Sapelli, an extreme citizen science data collection tool, in Cameroon, Brazil, and Congo; the Prey Lang app in Cambodia; and Humanitarian OpenStreetMap in Peru). The case studies reveal common interaction barriers and user requirements and subsequently Skarlatidou and Haklay (2021) provided a set of design, technological, and methodological recommendations relevant to the broader GCS context.

This article aims to extend current research by examining how Web-based GCS interfaces are used and the usability barriers that might affect the overall user experience. The methodology applied in this article has two parts. First, we perform a systematic search for Web-based GCS applications to identify geovisualization elements and provide an overview of their most common characteristics. For our systematic search we use SciStarter.org, which currently offers more than 1,000 citizen science projects. We group GCS projects based on common functionalities and introduce a three-level classification to capture different interactivity levels. In the second part we evaluate six GCS applications (i.e., two from each level of our classification) using the methods of heuristic evaluation and a cognitive walkthrough with the aim to identify common usability barriers that might influence the overall user experience. We discuss these two parts of our methodological approach in more detail in the next sections.

Methodology

SciStarter.org Systematic Search

SciStarter launched in 2014 and it hosts more than 1,000 citizen science projects and a community of 170,000 registered users (SciStarter 2024). Functioning as an online citizen science hub, the platform supports scientists and project leaders in launching new citizen science projects, sharing materials with a pool of participants, and collecting and sharing citizen science data. It also enables anyone interested in citizen science to search and contribute to projects that fit their search criteria (e.g., interest, geographic location). We opted for SciStarter.org due to its popularity and we used the platform to search specifically for GCS applications. SciStarter.org offers an advanced search feature (Figure 1) that facilitates

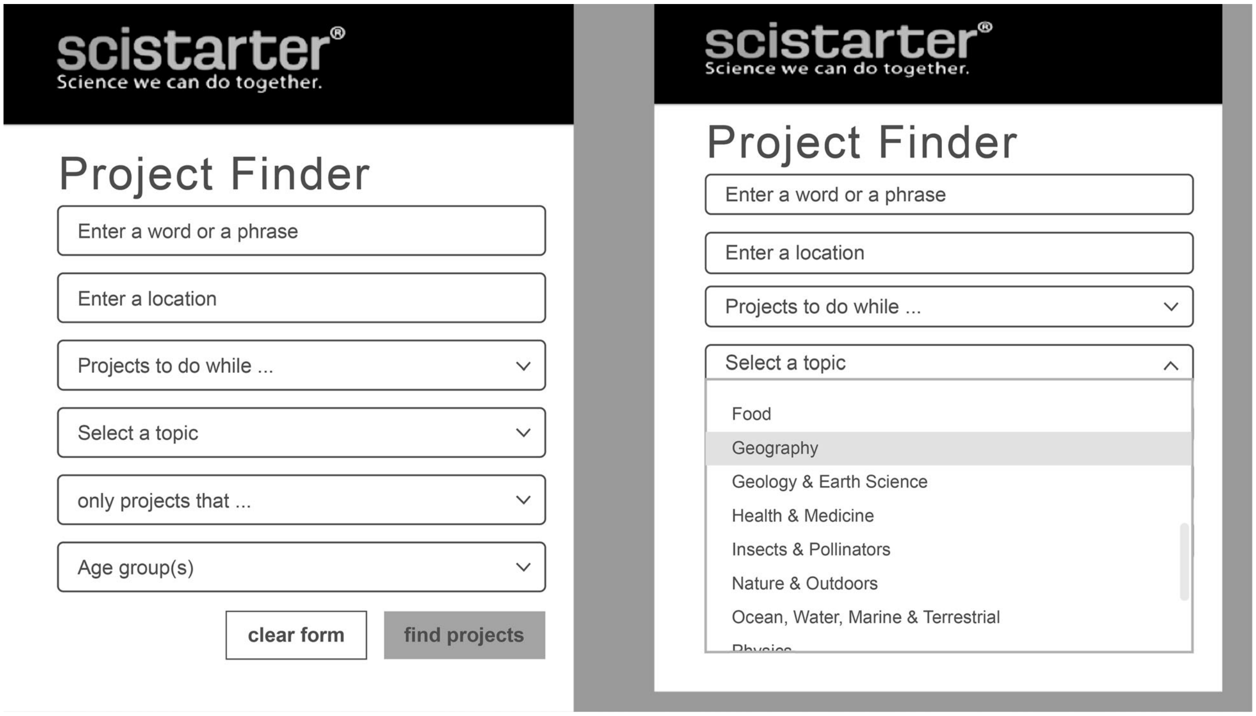


Figure 1. SciStarter.org: Project finder advanced search (as of June 2019). *Source:* SciStarter.org.

searching for citizen science projects based on different criteria (e.g., a keyword; a specific location; projects to contribute while on a walk, at school, at the beach, etc.; a specific topic; projects relevant to specific age groups; etc.).

The search was conducted by two researchers using different approaches in 2020. The first researcher manually browsed through all 1,467 projects offered by SciStarter.org at the time of the evaluation, to identify projects with a geographic component ($n = 345$). The second researcher used the advanced search function to search for "map" in the search box (Figure 1; $n = 91$) and to search for all projects under the "Geography" theme ($n = 51$). We then applied the following criteria to exclude (1) projects with access contingent on registration; (2) projects supporting only a mobile mapping component accessible via a mobile app; (3) instances of mapping components not loading properly or being under maintenance; and (4) projects without any contributions. As shown in Figure 2, the total number of GCS projects was 229 (i.e., after removing duplicated entries), which we subsequently analyzed further.

A thorough inspection of the geographic components followed, based on a checklist, which included project topic, geographic location, technology used to deliver online map (e.g., Google Maps Javascript application programming interface (API), ESRI ArcGIS Online, etc.), type(s) of basemaps (e.g., Google Satellite; Microsoft Bing Maps), map size (measured in different screen sizes; i.e., twenty and fourteen inches), geographic data (e.g., points, lines, polygons), search box, contributing spatial data via the Web-mapping component, adding data attributes using the Web-mapping component (e.g., videos, photos), zoom (in/out and to user's location), home option (i.e., back to default zoom level), drag map feature, move arrow (north, south, east, west), view options for data attributes (e.g., pop-up window, new page, link), draw feature, measure tool, filtering options, layer control folded/unfolded, legend, and scale bar. The inspection was carried out separately by the two researchers. Any disagreements in the analysis were discussed, and a final list was created for further analysis in the second part of our methodology.

Usability Expert Inspection Analysis

In the second part of our analysis an expert inspection was carried by two evaluators to assess the usability of the geographic component of six citizen science projects: Curio.xyz (Curio), CyanoTracker (CT), iMapInvasives (iMV), Kissing Bug and Chagas Disease

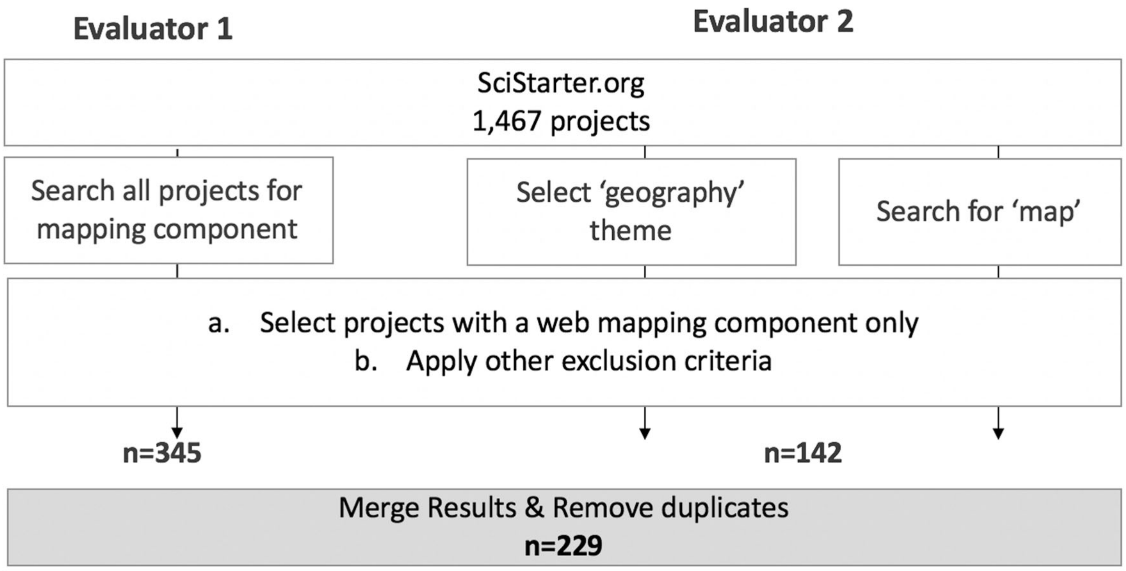


Figure 2. Search process carried out by two researchers.

(KB), iNaturalist's Wildlife Connectivity Project (iNat), and Tomnod (TN). It should be noted that since this evaluation took place, Curio, CT and TN have been retired. KB, iMV, and iNat still remain active, although their interfaces, including their geographic components, might have slightly changed.

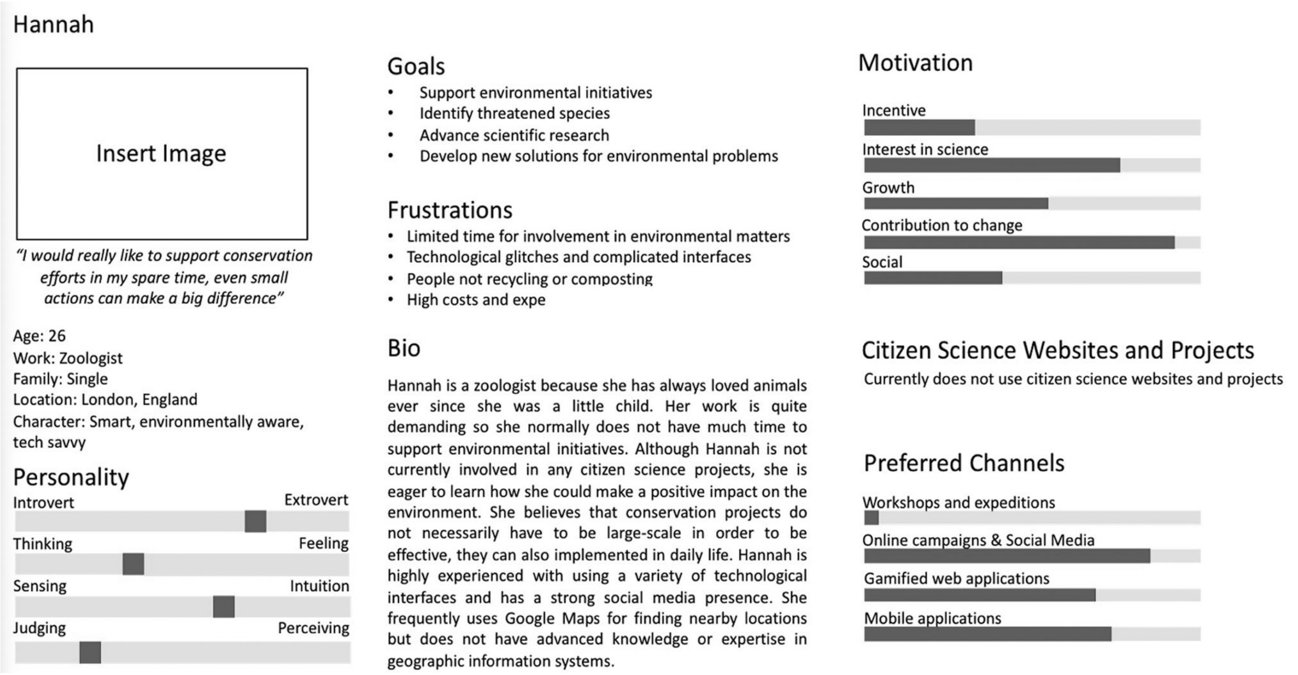
The expert inspection was based on two popular HCI methods: heuristic evaluation (HE) and cognitive walkthrough (CW). HE is a popular and informal inspection HCI method, where the evaluators judge the system based on a list of usability principles (Nielsen 1995). We included in our list of heuristics the design recommendations that target citizen science applications developed by Skarlatidou, Hamilton, et al. (2019) that were developed after an extensive review of relevant scholarship and usability user testing. These recommendations by Skarlatidou, Hamilton, et al. (2019) capture at a great level of detail common user expectations and functional requirements from citizen and GCS applications. To further ensure that the mapping component is sufficiently examined we decided to include in our heuristics the design guidelines proposed by Skarlatidou, Cheng, and Haklay (2013), which were built for Web-mapping sites that support members of the public participating in environmental decision-making processes. The combined list included seventy heuristics that guided the HE processes.

One limitation of HE is that the heuristics used do not explicitly target GCS applications. To address this limitation and further evaluate the overall user experience within specific contexts of use, we also used the CW method. Nielsen (1995) explained that CW is a method that simulates the users' problem-solving practices, while it investigates contextual details that cannot be easily identified with the HE. The CW evaluation was carried out by the same two evaluators who were also supplied with a persona-based scenario to reflect user needs and expectations. The persona (Figure 3) describes a tech-savvy, eco-conscious zoologist with a particular interest in scientific research and a frequent Google Maps user, but without any technical expertise in the use and development of geographic interfaces. Both evaluators used a severity rating scale from 1 (*very minor problem*) to 4 (*usability catastrophe*) to rate the identified problems.

Results

SciStarter.org Systematic Search Results

A total of 229 GCS projects were identified on SciStarter.org, with the majority ($n = 169$, ≈ 74 percent) exhibiting an ecological focus, and with most of these projects focusing on biodiversity monitoring, either through various species monitoring at a global scale, or more specific species monitoring in specific locations. Pollution data collection emerged as the second most popular theme ($n = 20$), followed by various environmental themes and one health-related project. Geographic distribution revealed a concentration of projects in the United States



Hannah

Insert Image

"I would really like to support conservation efforts in my spare time, even small actions can make a big difference"

Age: 26
Work: Zoologist
Family: Single
Location: London, England
Character: Smart, environmentally aware, tech savvy

Personality

Introvert – Extrovert
Thinking – Feeling
Sensing – Intuition
Judging – Perceiving

Goals

- Support environmental initiatives
- Identify threatened species
- Advance scientific research
- Develop new solutions for environmental problems

Frustrations

- Limited time for involvement in environmental matters
- Technological glitches and complicated interfaces
- People not recycling or composting
- High costs and expe

Bio

Hannah is a zoologist because she has always loved animals ever since she was a little child. Her work is quite demanding so she normally does not have much time to support environmental initiatives. Although Hannah is not currently involved in any citizen science projects, she is eager to learn how she could make a positive impact on the environment. She believes that conservation projects do not necessarily have to be large-scale in order to be effective, they can also implemented in daily life. Hannah is highly experienced with using a variety of technological interfaces and has a strong social media presence. She frequently uses Google Maps for finding nearby locations but does not have advanced knowledge or expertise in geographic information systems.

Motivation

Incentive
Interest in science
Growth
Contribution to change
Social

Citizen Science Websites and Projects

Currently does not use citizen science websites and projects

Preferred Channels

Workshops and expeditions
Online campaigns & Social Media
Gamified web applications
Mobile applications

Figure 3. Persona used for cognitive walkthrough implementation.

($n = 121$, ≈ 53 percent), which is not surprising, given the U.S. focus of SciStarter, and a large proportion having a global scope ($n = 57$; ≈ 25 percent). A smaller number of projects targeted specific regions such as Europe ($n = 14$) and Australia ($n = 22$), with minimal representation in other regions (i.e., Africa, Mexico, Cuba, and the Antarctic, with only one project in each of these regions).

During the SciStarter.org database search we observed that locating and accessing the geographic component was complex due to multiple terminologies being used (e.g., terms used include "GIS," "Explore the data," "Where to find," "Map," "Data," "Observations," "Data portal," "Results"; "Search species." "Playing With Data," "Sightings," "Local Chapters"). Interestingly, some GCS projects offer more than one geographic interface to support different tasks, targeting different audiences, and having a completely different look and feel, despite the fact that disparate interface designs might cause confusion to end users. For instance, the "Celebrate Urban Birds Platform"[1] project provided separate interfaces for participant mapping and species mapping, each employing distinct visualizations and functionalities.

A smaller number of projects use a map for data visualization purposes; for example, viewing data on a close to static map ($n = 25$, ≈ 11 percent) similar to the Lost Ladybug Project (Figure 4A), which provides no interactivity other than panning using the arrows at the three sides of the map. More than half of the projects use the geographic component to view data on a map with limited interactivity ($n = 156$, ≈ 68 percent), similar to the Whale Track Project (Figure 4B), which provides limited interactivity by clicking on individual data points. More sophisticated functionality for processing and analyzing data further (e.g., filtering data by various attributes, generation of statistical charts, drawing polygon boundaries on the map, and extracting data) is provided by thirty-seven applications; an example here is the Treezilla Project (Figure 4C), which provides more sophisticated interaction options such as advanced filtering and adding points directly onto the map. The rest provide dynamic maps with no interactivity, and some provide maps that support directly adding new observations but without any visualization capabilities. Only some projects facilitated location-based data entry ($n = 61$, ≈ 27 percent), with a significant portion ($n = 43$, ≈ 19 percent out of 27 percent) requiring user registration to access this feature, which can be explained as part of the data quality assurance practices within citizen science.

Interestingly, most projects have their own stand-alone Web mapping page, and only a few use mapping functionality provided via citizen science platforms such as iNaturalist, EpiCollect, MyWater,

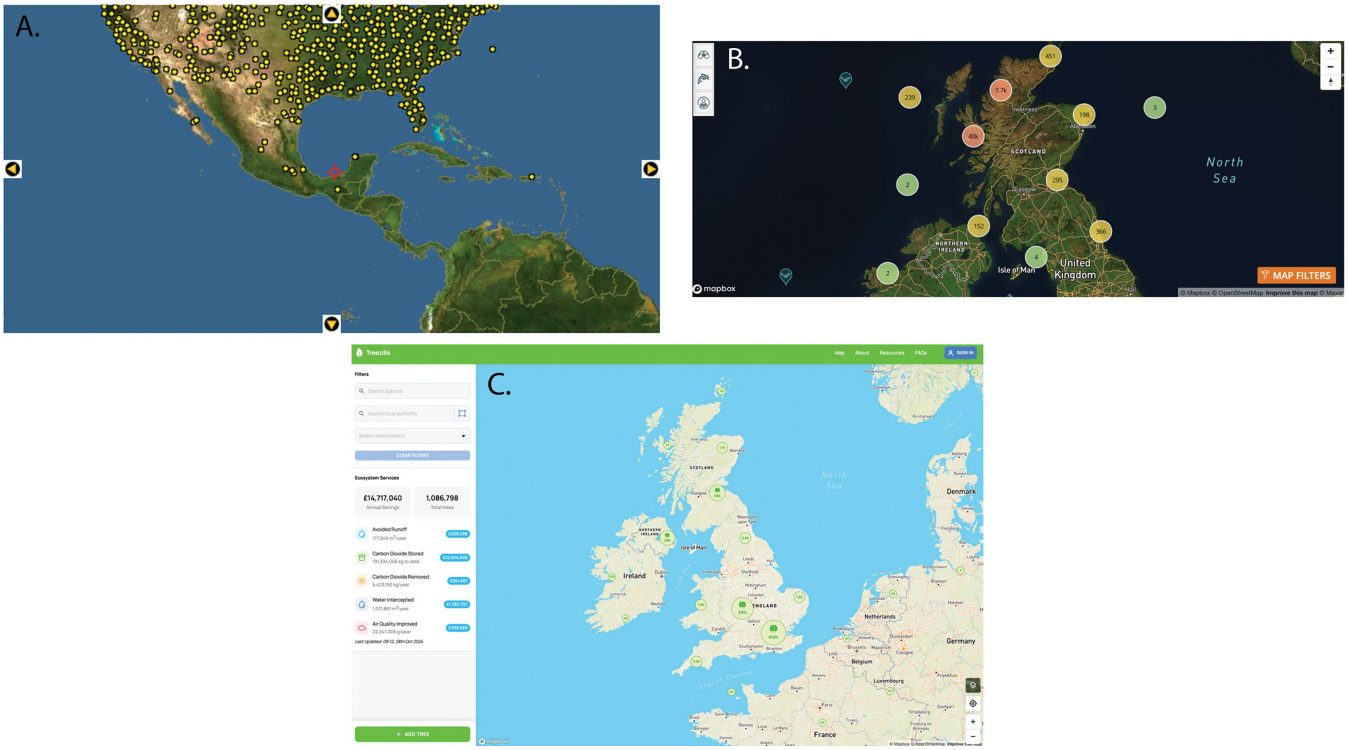


Figure 4. Geographic citizen science (GCS) projects with different interactivity options: (A) The Lost Ladybug Project (*Source:* www.lostladybug.org); (B) The Whale Track Project (*Source:* https://hwdt.org/whale-track); (C) Treezilla Project (*Source:* https://treezilla.org).

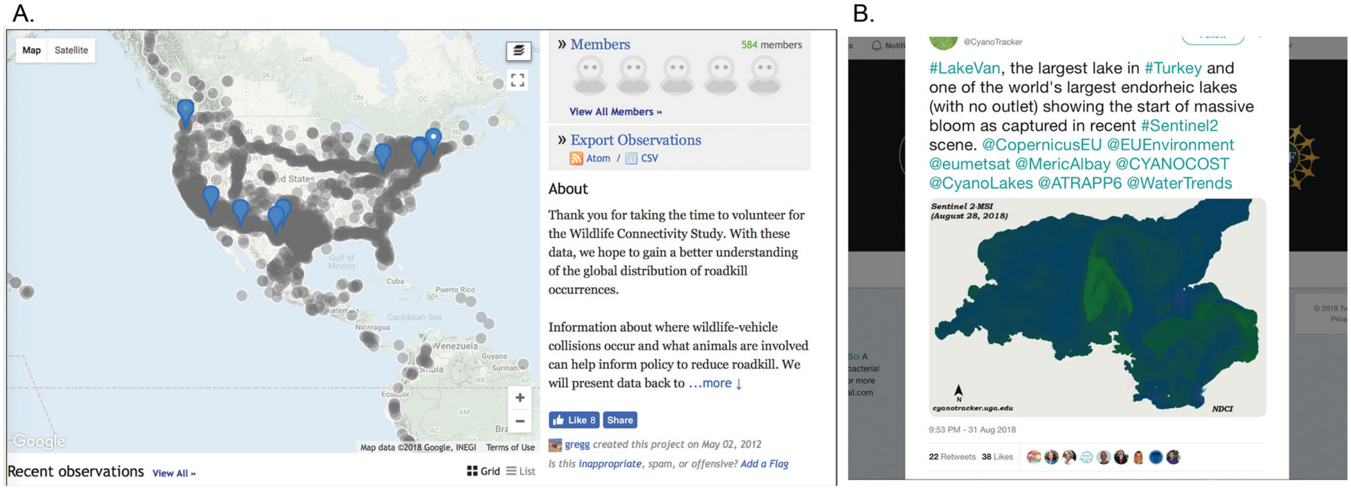
and OpenTreeMap. Over two thirds of the projects use the Google Maps Javascript API, followed by Leaflet's, Mapbox's and ESRI's APIs. The predominant method of visualizing geographic data across most projects is through points exclusively, with six projects incorporating both points and lines, and three projects using both points and polygons. Conversely, the employment of lines or polygons in isolation is less prevalent, observed in one and four projects, respectively. To mitigate data clutter and enhance map legibility, thirty-one projects employ point clustering techniques. With respect to data collection functionality, although not universally supported via the Web mapping interface, most projects enable users to collect point data, with seven projects only facilitating the addition of lines and polygons.

Following the initial screening of GCS projects on SciStarter.org, we categorized the geographic components of the applications in three broad categories based on the interactivity they support. From each category we selected two applications for further evaluation using HCI methods. To ensure the usability evaluation findings reflect the broader geovisualization practices, we selected a "best" and a "worst" case example to include in each category, based on the evaluators' initial assessment.

Level 1 supports basic functionality provided by the Web mapping API being utilized and the geographic component is used mainly for data visualization purposes.[2] From this level iNaturalist's Wildlife Connectivity Study (iNat; Figure 5A) and Cyanotracker (CT; Figure 5B) projects were selected to evaluate their usability and overall user experience.

In Level 2 we have two distinct types of GCS applications, which provide midlevel interaction with end users. First, we have applications such as Tomnod (TN; Figure 6A), where users participate in citizen science through microtasks that ask them to identify spatial objects on satellite imagery. Second, we have applications like Kissing Bugs and Chagas Disease (KB; Figure 6B), which provide midlevel functionality through mainly some sort of data filtering. TN and KB are the two applications from this category that were chosen to undergo further evaluation in the second part of this study.

Finally, Level 3 includes GCS projects with a more sophisticated geographic component in terms of design and functionality. For example, the iMapInvasive (iMV) project (Figure 7A), which collects invasive species data, has a large size Web mapping interface covering most of the user screen and



Thank you for taking the time to volunteer for the Wildlife Connectivity Study. With these data, we hope to gain a better understanding of the global distribution of roadkill occurrences.

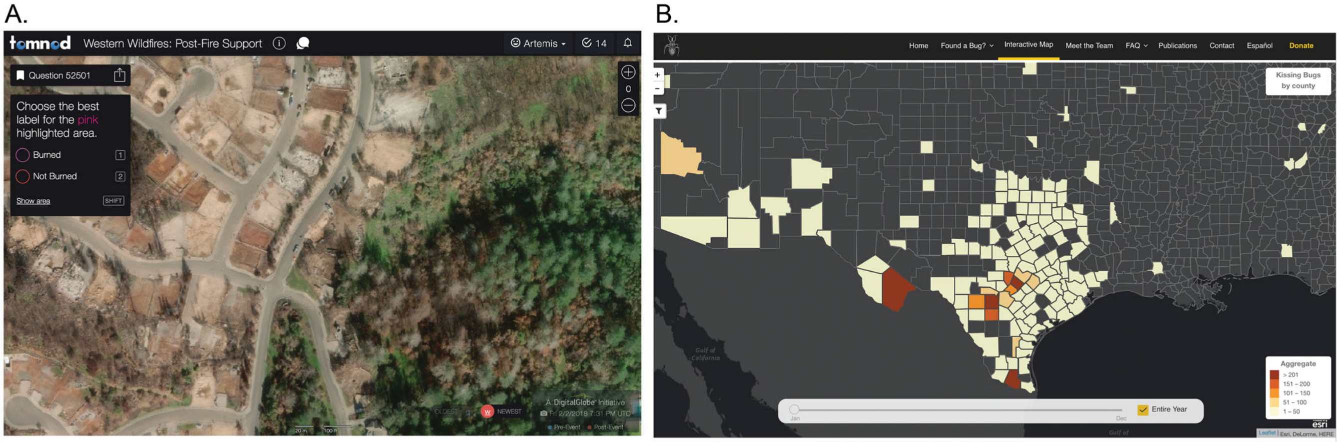
Information about where wildlife-vehicle collisions occur and what animals are involved can help inform policy to reduce roadkill. We will present data back to …more ↓

gregg created this project on May 02, 2012

Is this inappropriate, spam, or offensive? Add a Flag

#LakeVan, the largest lake in #Turkey and one of the world's largest endorheic lakes (with no outlet) showing the start of massive bloom as captured in recent #Sentinel2 scene. @CopernicusEU @EUEnvironment @eumetsat @MericAlbay @CYANOCOST @CyanoLakes @ATRAPP6 @WaterTrends

Figure 5. Level 1 projects: (A) iNaturalist's Wildlife Connectivity Study project (*Source:* www.inaturalist.org); (B) Cyanotracker project (*Source:* http://cyanotracker.uga.edu/; project now retired).



Choose the best label for the pink highlighted area.

Figure 6. Level 2 projects: (A) Tomnod—Western wildfires project, now retired (*Source:* Tomnod.com). (B) Kissing Bugs and Chagas Disease project (*Source:* https://kissingbug.tamu.edu).

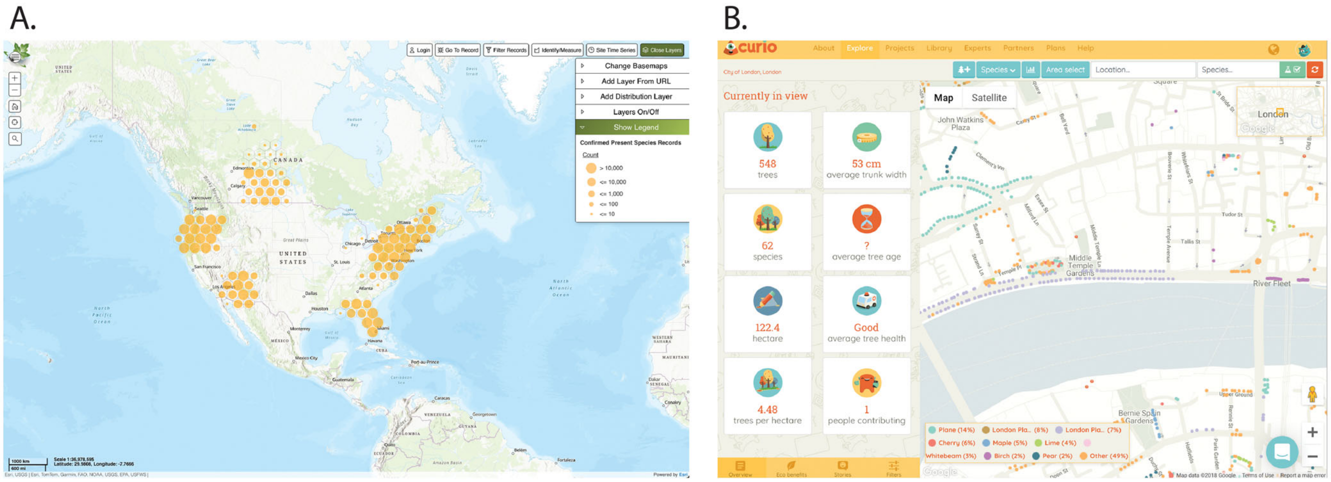


Figure 7. Level 3 projects. (A) iMapInvasives project (*Source:* https://www.imapinvasives.org). (B) Curio project, now retired (*Source:* https://www.curio-eco.com/).

provides more advanced functionality such as filtering data, interacting with individual observations, adding Web layers, identifying observations in specific locations, measuring distances, and more. Curio (Figure 7B) also at this level is a project for monitoring urban trees through which participants add tree observations (i.e., points together with photos or stories). The geographic component, which also covers most of the screen, provides functionality such as adding observations directly on the map, species and location filtering, interacting with data, and more. Curio and iMV were further evaluated for their usability and overall user experience in the second part of our methodology.

Usability Inspection Analysis Findings: Overview

Figure 8 summarizes the number of problems found with the HE. We expected that as the complexity of the geographic component increases usability becomes more problematic, but as can be seen from Figures 8 and 9, this was not entirely true. iMV from Level 3 scored the worst in terms of usability, with a total of sixty-seven problems and over half of those considered to be severe. Curio, on the other hand, also from Level 3, performed much better, with a total of twenty-six problems found, out of which twelve were considered to be severe. TN (Level 2) performed the best in terms of usability, with only fifteen total problems found (eight severe). Level 1 applications iNat and CN performed similarly, with fifty-two and fifty-seven usability problems found, respectively. Although iNat scored better in terms of usability compared to CN, it had a higher number of minor problems.

Figure 9 summarizes the CW findings. iMV performed the worst, with fifteen usability problems found, thirteen of which were considered severe. iNat scored second worst, followed by KB and CN. TN and Curio performed the best during the CW with four severe problems detected on each application. It can be seen from both the HE and CW evaluation results that the complexity of the mapping component does not directly influence the usability of the geographic component. CW findings were more specific to the context and revealed user frustrations, hence they tend to be mostly severe. We analyze and discuss the most important HE and CW findings in the next section.

Analysis of Usability and User Experience Problems and Opportunities for Improvement

Locating Project Information. The geospatial interface of most applications in Levels 2 and 3 appears to be the central component, enabling users to directly view or interact with data. This emphasis on the map, however, makes it challenging for users to locate information about the project, its objectives, and outputs, which does not adhere to relevant citizen science principles (Skarlatidou, Hamilton, et al. 2019). During the usability inspection, it was observed that many

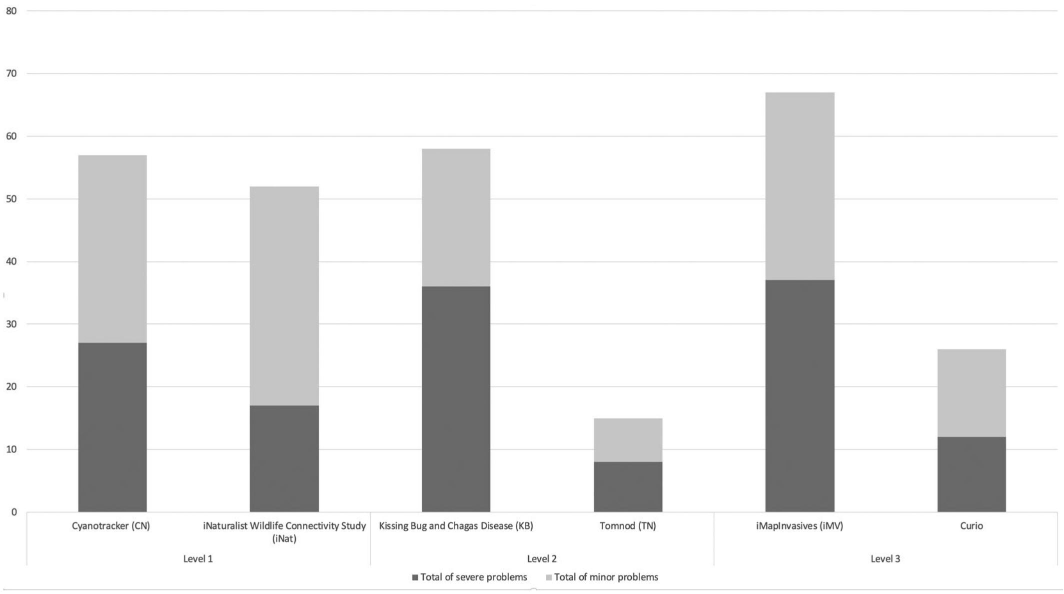


Figure 8. Problems found with heuristic evaluation.

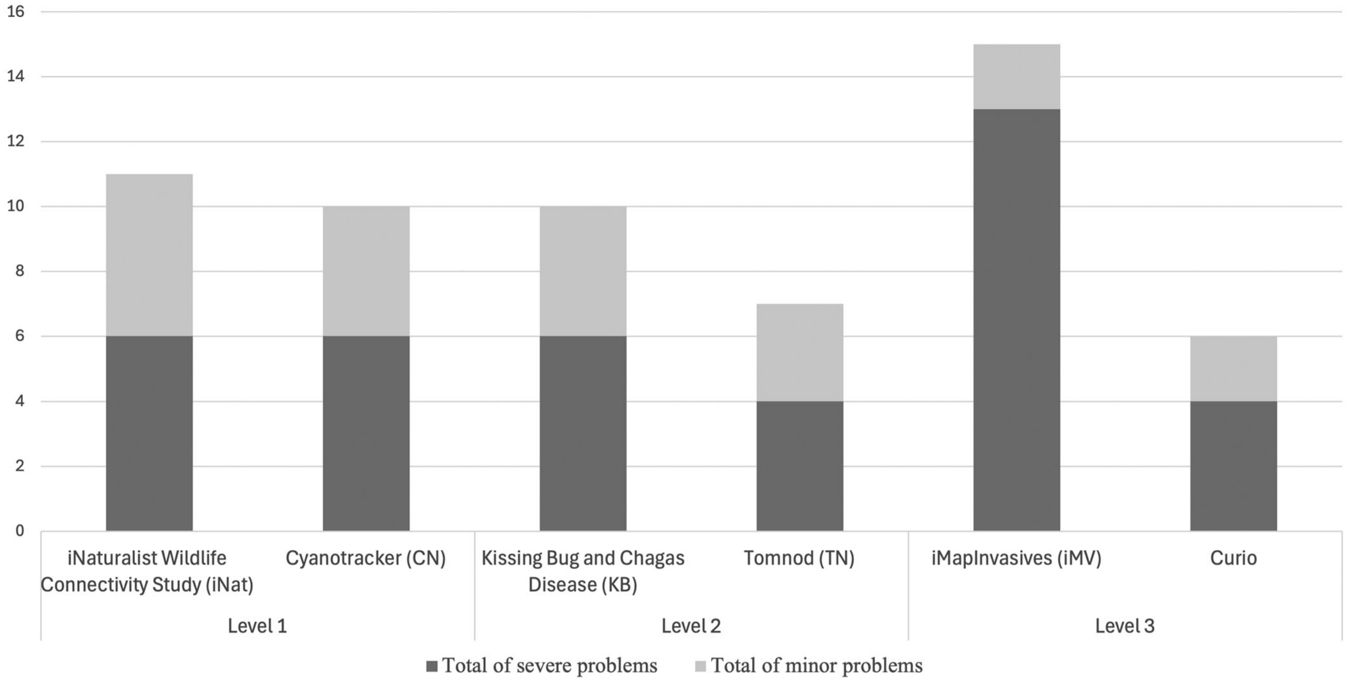


Figure 9. Problems found with cognitive walkthrough.

applications (e.g., Curio, KB) provide no clear and easy to access information about the project; some details were found on Curio after watching some videos. On the other hand, other projects include this information, but it is either hard to locate (e.g., in the case of TN) or it is provided on a separate Web page that features different design aesthetics, as is the case with iMV. Both evaluators commented that such design disparities across the mapping component and the rest of the Web pages create a sense of disconnection. This is less the case with projects from Level 1, where the geospatial component is not designed as the central component. The HE and CW also found that the Web interfaces for most Level 2 and 3 projects have confusing menus, which are not grouped in a logical manner, and this adds to the complexity of locating the map and other relevant information.

Provision of Registration and Multiple Sign-in Options. With respect to the overall interface design and functionality, it should be noted that the lack of registration or an option to sign in using social media was found to be problematic, with a negative impact on the overall user experience. For example, KB users have the option to fill in an online form to submit new data; every time a new observation is submitted, they need to enter their e-mail address and personal details, as there is no mechanism for the system to retain this information. Conversely, projects like TN, which aim to support humanitarian causes, could benefit significantly from incorporating social media sign-in options if data privacy is not a concern. This feature would not only enhance the user experience by streamlining data submission, but also enable users to share their contributions with their social networks, potentially increasing project visibility and engagement.

Community-Building Features in the Mapping Interface. Another prevalent issue observed was the absence of community-building features across most projects, such as forums or the ability to add comments to contributed data via the mapping interface, which is a common expectation among citizen science participants (Skarlatidou, Hamilton, et al. 2019). This lack of community engagement tools was particularly notable in all projects other than iNat, which already provides such functionality. The importance of fostering a sense of community varies depending on the project's objectives. For instance, in Curio, where the primary goal is to collect information and stories about local trees, community-building aspects should have been more prominently featured in the platform's design. Specifically, users should have had the option to select and view trees with existing contributions and engage with others through their own contributions, thereby facilitating the creation of collective community stories on the map.

Conversely, for projects like TN that involve small, repetitive tasks, the emphasis on community-building features via the geographic component might be less crucial. It is essential to acknowledge here that such features can greatly benefit novice users by enabling them to provide more accurate data and fostering a sense of community belonging, which is a significant motivator in citizen science participation.

Complex Terminology. The use of complex and scientific terminology is particularly problematic when it exists in online forms for contributing new observations or in data filtering options. For example, iMV's online form for data submission is long, with many fields that need to be filled by end users, feature scientific terminology, and include the requirement to input the Global Positioning Ssystem coordinates for each observation submitted. This requirement might not be intuitive for users when submitting data via a Web-based interface. Similarly, scientific terminology is employed in data filtering, potentially confusing novice users as evidenced by iMV.

Data Visualization. When it comes to the geospatial component, it was found that applications heavily rely on point data in their visualizations, where data clustering plays a crucial role in terms of improving usability. iMV and KB aggregate point data in polygons for their visualization, which was found to affect usability severely.

For KB this might have been thought of as a solution to privacy concerns as people are most likely to report bugs found in their homes or gardens. Nevertheless, users are unable to view their individual contributions and data attributes, verify their data entries, or get credit for their contributions. Furthermore, this visualization method limits users' understanding of the data despite the multiple filtering options provided, thereby hindering the project's educational and engagement aspects. To address privacy concerns without sacrificing usability, alternative geovisualization options should be explored, which would still allow users to maintain a sense of data ownership, and further facilitate exploration, analysis, and interaction with other users. It should be noted here that iMV offers additional data access after registration, although this aspect was not explored further due to methodological constraints.

For projects like TN—which operate a volunteer thinking type of citizen science projects (Haklay 2021)—users interact with satellite imagery to identify objects on the map in geographic areas where limited or no data are available (e.g., to support humanitarian interventions). In such cases, the geographic area that the users are asked to identify spatial objects, which is most likely unfamiliar to them, is illustrated with a bright pink polygon boundary. The evaluators found that despite the color choice, it is still easy to miss the feature when the user changes zoom level or scrolls around the map. Implementing an option to return to the original "map view" would improve usability. Additionally, evaluators suggested that projects like TN could benefit from displaying metrics indicating the amount of data needed until project completion and the volunteer's contribution toward the cause, similar to Humanitarian OpenStreetMap's Tasking Manager feature, which shows the percentages completed for a project and disaggregates the need spatially through a simple map grid. It is believed that such metrics do not only provide users with a sense of progress but also encourage continued participation and foster a sense of accomplishment and community engagement within the project.

Map Design and Functionality. Map design for most GCS components in our analysis typically relies on very pale or dark color combinations, which can present challenges for a significant portion of users, particularly those with color deficiency, affecting 8.0 percent of males and 0.5 percent of females in the population (Birch n.d.). Geographers and cartographers have extensively investigated geovisualization issues with respect to cognition and emotions (see, e.g., Skarlatidou et al. 2011; Fabrikant et al. 2012; Griffin 2017; Tomio (Weninger) 2017; Kushkin et al. 2023) and tools like ColorBrewer.org (Harrow and Brewer 2013) have been developed to support more effective map design. The research insights from these studies could potentially inform the development of more user-friendly GCS visualizations.

Moreover, our usability inspection found that the design of graphical scales is poor and legends are mostly absent or provided as a folded layer option visible only if users locate this feature (e.g., Curio, iMV, iNat). Another usability issue identified during the evaluation was that selected map objects are not highlighted so it is harder to locate them on the map (e.g., in iMV, Curio, KB). CW further revealed that users might wish to interact with observations shown on the map by adding comments, annotating data (a feature that is currently supported by iNat only), or adding pictures and audio files. These interactions have the potential to enhance scientific understanding, promote collective environmental action, and enrich the quantity and quality of data. Subsequently, they can contribute to a user experience that is more enjoyable and engaging for end users.

Metadata and Other Information for Geospatial Features. A well-established usability heuristic from the geospatial context emphasizes the provision of easy-to-access metadata, which in this instance would include information about when data were added and who collected and edited the data, among others. Such information for most GCS applications is not readily available, however (e.g., Curio, iMV, KB). For KB and iMV this proved to be particularly problematic due to the approach chosen to visualize data (see the "Data Visualization" section). Similarly, almost no project provides any in-depth information about geospatial features, data accuracy issues, how the maps were constructed, and so on. Public participation geographic information systems (PPGIS) scholars have underscored the significance of providing such information to help nonexperts develop rational trust perceptions, thereby improving transparency in decision and policymaking (Sieber 2006; Brown and Kyttä 2014). Despite the equal importance of trust in science (epistemic trust) and citizen science, the provision of such information is often overlooked by most citizen science projects. This oversight not only hampers users' ability to evaluate the reliability of the data but also could negatively affect trust in the project and data.

Discussion

The results of our analysis of 229 GCS projects on SciStarter.org reveal interesting insights about the current state of GCS with respect to usability and the overall user experience these applications offer. We found that most GCS projects on CitSci.org have a biodiversity monitoring focus and that geographically they are concentrated in the United States followed by a significant number of projects with a global scope. This trend is consistent with the exponential growth of citizen science in environmental and ecological sciences during the last years (Pocock et al. 2017). Citizen science projects in this context predominantly take the form of contributory projects (Shirk et al. 2012), where volunteers mainly contribute point data. Considering the inherent spatial data characteristics of environmental data, it is not surprising that geospatial technologies are heavily used here to support data collection, dissemination, and occasionally data processing.

Based on Shirk et al.'s (2012) typology, citizen science could also take the form of collaborative and cocreated projects where people are involved in various stages of the scientific process (e.g., from defining the research questions and designing the study all the way to analyzing, interpreting, discussing, and even publishing the results). Although we did not identify any collaborative and cocreated GCS projects on SciStarter.org to include in our analysis, it would be reasonable to assume that projects with a deeper engagement of volunteers in the scientific process might require more sophisticated interaction with the geospatial component. Nevertheless, we found that GCS projects regardless of their intended impacts (i.e., scientific, policy, engaging, or educational; Geoghegan et al. 2016) or the depth of engagement they support (i.e., contributory, collaborative, cocreated projects) should provide sufficient levels of interaction to engage, educate, and support people's needs and expectations. To achieve this, geospatial interfaces should facilitate visual thinking, which, according to Roth (2016) is "best supported through high levels of human–map interaction" (71) to shift from one-way information sharing (i.e., citizens as sensors; Goodchild 2007) to knowledge coproduction that could occur at multiple formal or informal societal and scientific settings.

DiBiase (1990), in his popular Swoopy diagram, explained how geovisualization is used to support the scientific process; he distinguishes the process across private (e.g., scientific, policy) and public realms where the former emphasizes visual thinking through exploration and confirmation and the latter emphasizes visual communication via synthesis and presentation. Citizen science not only blurs these boundaries across private scientific and public realms, but lay people are involved in data collection, which precedes data processing and analysis. Many GCS volunteers seek immediate access to view data (Pejovic and Skarlatidou 2020), reflecting a sense of data ownership and the desire to engage in visual thinking processes. For example, iNaturalist's Wildlife Connectivity Project (Level 1) has evolved its geospatial component, as this evaluation took place, to support both visual thinking and communication, aligning better the design of the geospatial component with the project's intended impacts. On the other hand, projects like Tomnod and Curio.xyz (Levels 2 and 3) might face challenges in providing adequate interactivity to meet project aims and user expectations with respect to sufficient visual thinking and communication processes. From these examples, it should be clear that providing more functionality is not necessarily better. High levels of human–map interaction in a GCS context might still be insufficient in terms of supporting visual thinking if user expectations are not fully considered and integrated into the design of the geospatial component. Moreover, with over half of the identified projects using a visual communication approach this reveals a significant limitation for GCS.

We therefore make two recommendations. First, contributory GCS projects need to better support visual thinking. This means that functionality should go beyond merely contributing or viewing data to facilitate various forms of knowledge coproduction, both at the project and user level. This approach should be prioritized even if it is not initially seen as an immediate priority or directly aligned with project objectives by relevant decision makers. Second, a user-centered design (UCD) process should be more widely applied to inform the design of the geospatial interfaces in citizen science from the early stages. This is particularly beneficial for identifying user requirements related to visual thinking functionalities and geovisualization options, tailored to the specific project context. The importance of UCD is even greater for projects that opt to develop their own stand-alone Web or mobile mapping interfaces, as it ensures that the design meets the unique needs of users and the project's goals.

A significant finding across many applications was the lack of information regarding spatial data accuracy and the methods used to construct maps. This is particularly critical for projects that do not directly visualize the original contributions but process data prior to showing them back to users, such as iMV and KB. This approach raises ethical concerns that must be carefully addressed in this context. We are not only referring to the well-discussed ethical issue of overloading participants with unpaid work without providing recognition or attribution through the simplest form of displaying their data on a map (Guerrini et al. 2021). We also want to highlight the negative impact that such visualization choices might have on volunteers, including their knowledge, affective, and embodied experiences with local environments and their motivations (Skarlatidou, Ponti, et al. 2019).

Scholarship in critical GIS and participatory mapping discusses the role of the map as a social construction and human practice, reflecting multiple power–knowledge dynamics (Crampton 2001). Because GCS exemplifies many similarities as a form of participatory research, it should seek to expand participants' access to and control over the information produced, including a greater range of types and sources of knowledge (Elwood 2006). Moreover, Feick and Robertson (2021) suggested that GCS tools should be designed and implemented to leverage and develop geographic expertise and local knowledge. In the development of two GCS applications, they further described how attention to geographic expertise in data collection resulted in higher levels of interactivity and new functionality being introduced following a UCD process, eventually transforming an initially contributory project into a cocreated initiative, effectively supporting visual thinking. In this context, the presence of community-building features incorporated into the geospatial interface not only will help improve the quality and quantity of contributed data, but it might also foster a sense of belonging and motivation among users and could have a positive impact on the overall success and sustainability of the citizen science initiative. A UCD process should further reveal participants' privacy and data sharing concerns from the early stages (e.g., when GCS applications are used to engage local communities and individuals in collecting highly sensitive local data as in Hoyte 2021) and subsequently make an informed decision to incorporate or impede the use of such data-sharing features and functionality.

Citizen science applications need to better incorporate cartographic principles in the design of their geographic components. For example, scales and legends should be better communicated and should be visible at all times. Finally, in cases where the map serves as the central element of the project's online platform, special attention should be given to ensure consistent design across all Web pages, a user-friendly navigation menu, and avoiding complex terminology, especially within data filtering mechanisms and online forms for submitting new observations. User-friendly registration and sign-in options might also be particularly important, not only in terms of simplifying the data collection process, but further sustaining participation as well as attracting new participants.

Conclusions

Scientific institutions, governments, and international organizations increasingly recognize the value of citizen science in democratizing science, creating more inclusive scientific research agendas, informing evidence-based policymaking, and supporting social innovation (Fraisl et al. 2022). Citizen science is already treated as a major vehicle in the delivery of the 2030 Agenda for Sustainable Development, helping scientists to collect data at previously unprecedented spatiotemporal scales and, by doing so, aid exploration of some of the most stressing global challenges our societies are facing. A growing number of citizen science initiatives use geographic information technology to collect, process, visualize, and disseminate data. Although this utilization of geographic interfaces offers immense potential for scientific advancement and social change, GCS applications can only fulfill these objectives if they are user-friendly, are inclusive, and provide a rewarding and positive user experience, which fully considers end-user needs and expectations.

As we have demonstrated, this is a complex process and currently there are significant interaction barriers preventing participants from fully engaging with contributory GCS applications. Our study provides a set of recommendations and insights, which can help eliminate some of these barriers and improve interaction with GCS maximizing the potential of citizen science, but which can also inform the design of other participatory geographic tools. We recognize that further research is needed toward this direction, and this requires a closer collaboration across the geographic and citizen science communities. Geographic research focusing on geovisualization and human–map interaction can profoundly influence the design and implementation of more user-friendly GCS applications; yet this needs to be done in a context where the opportunities and constraints inherent to citizen science endeavors are fully understood and considered in providing relevant design and functionality solutions. Future research studies, among others, should further explore in more detail the geographic components of mobile GCS apps, collaborative and cocreated GCS projects, and GCS applications that are used outside environmental and ecological sciences (e.g., health), as these could have their own set of unique characteristics that might affect end users' needs and expectations and overall interaction.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

The development of this article was supported by European Union's Horizon Europe Research and Innovation Program under Grant Agreement No. 824580, Project European Citizen Science, Grant Agreement No. 101058509, and the ERC Advanced Grant Project European Citizen Science: Analysis and Visualisation under Grant Agreement No. 694767.

Notes

1. Celebrate Urban Birds Project (see https://celebrateurbanbirds.org).
2. It should be noted that since this evaluation took place iNat has extended the provided functionality significantly to include many different search and filtering options.

References

Andrienko, N., G. Andrienko, H. Voss, F. Bernardo, J. Hipolito, and U. Kretchmer. 2002. Testing the usability of interactive maps in common GIS. *Cartography and Geographic Information Science* 29 (4):325–42. doi: 10.1559/152304002782008369.

Antoniou, V., and C. Potsiou. 2021. Design and development of geographic citizen science: Technological perspectives and considerations. In *Geographic citizen science design: No one left behind*, ed. A. Skarlatidou and M. Haklay, 38–55. London: UCL Press.

Atzmanstorfer, K., A. Eitzinger, B. E. Marin, A. Parra Arteaga, B. Gonzalez Quintero, and R. Resl. 2016. HCI: Evaluation of the GeoCitizen-reporting app for citizen participation in spatial planning and community management among members of marginalized communities in Cali, Colombia. *GI_Forum* 4 (1):117–32. doi: 10.1553/giscience2016_01_s117.

Audubon.org. 2024. Audubon Christmas bird count results. Accessed August 2, 2024. https://netapp.audubon.org/cbcobservation/.

Benyei, P., A. Skarlatidou, D. Argyriou, R. Hall, I. Theilade, N. Turreira-García, D. Latreche, A. Albert, D. Berger, M. Cartró-Sabaté, et al. 2023. Challenges, strategies, and impacts of doing citizen science with marginalised and indigenous communities: Reflections from project coordinators. *Citizen Science: Theory and Practice* 8 (1):21. doi: 10.5334/cstp.514.

Birch. n.d. A significant percentage of the population is red-green colour blind. Why, then, did these two colours become accepted as safety signals? *The* Guardian. Accessed May 1, 2024. https://www.theguardian.com/notesandqueries/query/0,-1327,00.html.

Brown, G., and M. Kyttä. 2014. Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography* 46:122–36. doi: 10.1016/j.apgeog.2013.11.004.

Butt, M. A., and S. Li. 2015. Usability evaluation of collaborative PPGIS—GeoCWMI for supporting public participation during municipal planning and management services. *Applied Geomatics* 7 (3):139–61. doi: 10.1007/s12518-014-0141-0.

Çöltekin, A., B. Heil, S. Garlandini, and S. I. Fabrikant. 2009. Evaluating the effectiveness of interactive map interface designs: A case study integrating usability metrics with eye-movement analysis. *Cartography and Geographic Information Science* 36 (1):5–17. doi: 10.1559/152304009787340197.

Corbett, J. M., and C. P. Keller. 2005. An analytical framework to examine empowerment associated with participatory geographic information systems (PGIS). *Cartographica: The International Journal for Geographic Information and Geovisualization* 40 (4):91–102. doi: 10.3138/J590-6354-P38V-4269.

Crampton, J. W. 2001. Maps as social constructions: Power, communication, and visualisation. *Progress in Human Geography* 25 (2):235–52. doi: 10.1191/030913201678580494.

DiBiase, D. 1990. Visualization in the earth sciences. *Earth and Mineral Sciences:* Bulletin of the College of Earth and Mineral Sciences, *The Pennsylvania State University* 59 (2):13–18.

Dickinson, J. L., J. Shirk, D. Bonter, R. Bonney, R. L. Crain, J. Martin, T. Phillips, and K. Purcell. 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment* 10 (6):291–97. doi: 10.1890/110236.

Dinneen, J. 2020. Covid-19 can't stop citizen science. *Undark*. Accessed April 25, 2024. https://undark.org/2020/04/17/covid-19-citizen-science/.

Eitzel, M. V., J. L. Cappadonna, C. Santos-Lang, R. E. Duerr, A. Virapongse, S. E. West, C. C. M. Kyba, A. Bowser, C. B. Cooper, A. Sforzi, et al. 2017. Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice* 2 (1):1–20. doi: 10.5334/cstp.96.

Elwood, S. 2006. Negotiating knowledge production: The everyday inclusions, exclusions, and contradictions of participatory GIS research. *The Professional Geographer* 58 (2):197–208. doi:10.1111/j.1467-9272.2006.00526.x.

European Commission. 2018. *Directorate-general for research and innovation, OSPP-REC – Open science policy platform recommendations*. Luxembourg: Publications Office. Accessed December 11, 2023. https://data.europa.eu/doi/10.2777/958647.

Fabrikant, S., S. Christophe, G. Papastefanou, and S. Lanini-Maggi. 2012. Emotional response to map design aesthetics. Paper presented at the 7th International Conference on GIScience 2012, Columbus, OH, September 18–21.

Fecher, B., and S. Friesike. 2014. Open science: One term, five schools of thought. In *Opening science*, ed. S. Bartling and S. Friesike, 17–47. Cham, Switzerland: Springer.

Feick, R., and C. Robertson. 2021. Geographic expertise and citizen science: Planning and co-design implications. In *Geographic citizen science design: No one left behind*, ed. A. Skarlatidou and M. Haklay, 107–30. London. UCL Press.

Fraisl, D., G. Hager, B. Bedessem, M. Gold, P.-Y. Hsing, F. Danielsen, C. B. Hitchcock, J. M. Hulbert, J. Piera, H. Spiers, et al. 2022. Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers* 2 (1):1–20. doi: 10.1038/s43586-022-00144-4.

Funtowicz, S. O., and J. R. Ravetz. 1993. Science for the postnormal age. *Futures* 25 (7):739–55. doi: 10.1016/0016-3287(93)90022-L.

Geoghegan, H., A. Dyke, R. Pateman, S. West, and G. Everett. 2016. Understanding motivations for citizen science. Final report on behalf of the UK Environmental Observation Framework, UKEOF. Accessed May 1, 2024. https://www.ukeof.org.uk/resources/citizen-science-resources/MotivationsforCSREPORTFINALMay2016.pdf.

Goodchild, M. F. 2007. Citizens as sensors: The world of volunteered geography. *GeoJournal* 69 (4):211–21. doi: 10.1007/s10708-007-9111-y.

Griffin, A. 2017. Cartography, visual perception and cognitive psychology. In *The Routledge handbook of mapping and cartography*, ed. A. Kent and P. Vujakovic, 44–54. London and New York: Routledge.

Guerrini, C. J., N. L. Crossnohere, L. Rasmussen, and J. F. P. Bridges. 2021. A best–worst scaling experiment to prioritize concern about ethical issues in citizen science reveals heterogeneity on people-level v. data-level issues. *Scientific Reports* 11 (1):19119. doi: 10.1038/s41598-021-96743-4.

Haklay, M. 2021. Geographic citizen science: An overview. In *Geographic citizen science design: No one left behind*, ed. A. Skarlatidou and M. Haklay, 38–55. London: UCL Press.

Haklay, M., D. Dörler, F. Heigl, M. Manzoni, S. Hecker, and K. Vohland. 2021. What is citizen science? The challenges of a definition. In *The science of citizen science*, ed. K. Vohland, A. Land-Zastra, L. Ceccaroni, R. Lemmens, J. Perello, M. Ponti, R. Samson, K. Wagenknecht, 13–33. Springer. doi: 10.1007/978-3-030-58278-4.

Haklay, M., and C. Tobón. 2003. Usability evaluation and PPGIS: Towards a user-centred design approach. *International Journal of Geographical Information Science* 17 (6):577–92. doi: 10.1080/1365881031000114107.

Hennig, S., F. Zobl, and W. W. Wasserburger. 2017. Accessible web maps for visually impaired users: Recommendations and example solutions. *Cartographic Perspectives* 88:6–27.

Howe, J. 2006. The rise of crowdsourcing. *Wired Magazine* 14 (6):176–83.

Hoyte, S. 2021. Co-designing extreme citizen science projects in Cameroon: Biodiversity conservation led by local values and indigenous knowledge. In *Geographic citizen science design: No one left behind*, ed. A. Skarlatidou and M. Haklay, 38–55. London: UCL Press.

Irwin, A. 1995. *Citizen science: A study of people, expertise and sustainable development*. London: Burns & Oates.

Jasanoff, S. 2003. Technologies of humility: Citizen participation in governing science. *Minerva* 41 (3):223–44. doi: 10.1023/A:1025557512320.

Kushkin, A., A. Giordano, A. Griffin, and A. Savelyev. 2023. Cognitively congruent color palettes for mapping spatial emotional data: Matching colors to emotions. *Cartographic Perspectives* 102:38–62. doi: 10.14714/CP102.1821.

Lamourex, Z., and V. Fast. 2019. The tools of citizen science: An evaluation of map-based crowdsourcing. *Spatial Knowledge and Information Canada* 7 (4):1–7.

Meng, Y., and J. Malczewski. 2009. Web-PPGIS usability and public engagement: A case study in Canmore, Alberta, Canada. *CyberGeo: European Journal of Geography* 483:1–5. doi: 10.4000/cybergeo.22849.

Newman, G., D. Zimmerman, A. Crall, M. Laituri, J. Graham, and L. Stapel. 2010. User-friendly Web-mapping: Lessons from a citizen science website. *International Journal of Geographical Information Science* 24 (12):1851–69. doi: 10.1080/13658816.2010.490532.

Nielsen, J. 1995. Usability inspection methods. In *Proceedings of CHI '95 Conference Companion on Human Factors in Computing Systems*, ed. I. Katz, L. Mack, and R. Marks, 377–78. Boston Association for Computer Machinery.

Nivala, A.-M. 2007. Usability perspectives for the design of interactive maps. PhD diss., Helsinki University of Technology.

Nivala, A.-M., S. Brewster, and T. L. Sarjakoski. 2008. Usability evaluation of web mapping sites. *The Cartographic Journal* 45 (2):129–38. doi: 10.1179/174327708X305120.

Oxford English Dictionary. 2014. Citizen science. Accessed January 10, 2024. https://www.oed.com/view/Entry/33513?redirectedFrom=citizen+science-eid316619123.

Owen, R., P. Macnaghten, and J. Stilgoe. 2012. Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy* 39 (6):751–60. doi: 10.1093/scipol/scs093.

Parker, C. J. 2014. *The fundamentals of human factor design for volunteered geographic information*. Cham, Switzerland: Springer International.

Pejovic, V., and A. Skarlatidou. 2020. Understanding interaction design challenges in mobile extreme citizen science. *International Journal of Human–Computer Interaction* 36 (3):251–70. doi: 10.1080/10447318.2019.1630934.

Pocock, M., J. Tweddle, J. Savage, L. D. Robinson, and H. E. Roy. 2017. The diversity and evolution of ecological and environmental citizen science. *PLoS ONE* 12 (4):e0172579. doi: 10.1371/journal.pone.0172579.

Preece, J. 2016. Citizen science: New research challenges for human–computer interaction. *International Journal of Human–Computer Interaction* 32 (8):585–612. doi: 10.1080/10447318.2016.1194153.

Roger, E., C. Slatyer, and D. Kellie. 2023. Citizen scientists collect more nature data than ever, showing us where common and threatened species live. *The Conversation*. Accessed April 25, 2024. https://www.csiro.au/en/news/all/articles/2023/september/citizen-science-naturalists.

Roth, R. 2013. Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science* 6 (6):59–115. doi: 10.5311/JOSIS.2013.6.105.

Roth, R. E. 2016. Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science* 6:59–115. doi:10.5311/JOSIS.2013.6.105.

SciStarter. 2024. The SciStarter ecosystem. Accessed April 20, 2024. https://scistarter.org/about.

Shirk, J. L., H. L. Ballard, C. C. Wilderman, T. Phillips, A. Wiggins, R. Jordan, E. McCallie, M. Minarchek, B.V. Lewenstein, M. E. Krasny, and R. Bonney. 2012. Public participation in scientific research: A framework for deliberate design. *Ecology and Society* 17 (2):29. doi: 10.5751/ES-04705-170229.

Shneiderman, B. 2008. Science 2.0 Copernican challenges face those who suggest that collaboration, not computation are the driving energy for socio-technical systems that characterize Web 2.0. *Science* 319 (5868):1349–50. [Mismatch] doi: 10.1126/science.1153539.

Sieber, R. 2006. Public participation geographic information systems: A literature review and framework. *Annals of the Association of American Geographers* 96 (3):491–507. doi: 10.1111/j.1467-8306.2006.00702.x.

Sieber, R. E., and M. Haklay. 2015. The epistemology(s) of volunteered geographic information: A critique. *Geo: Geography and Environment* 2 (2):122–36. doi: 10.1002/geo2.10.

Skarlatidou, A., T. Cheng, and M. Haklay. 2013. Guidelines for trust interface design for public engagement Web GIS. *International Journal of Geographical Information Science* 27 (8):1668–87. doi: 10.1080/13658816.2013.766336.

Skarlatidou, A., and M. Haklay. 2006. Public Web mapping: Preliminary usability evaluation. Paper presented at GIS Research UK Conference, Nottingham, UK, April 5–7.

Skarlatidou, A., and M. Haklay. 2021. *Geographic citizen science design: No one left behind*. London: UCL Press.

Skarlatidou, A., A. Hamilton, M. Vitos, and M. Haklay. 2019. What do volunteers want from citizen science technologies? A systematic literature review and best practice guidelines. *Journal of Science Communication* 18 (1):A02. doi: 10.22323/2.18010202.

Skarlatidou, A., M. Ponti, J. Sprinks, C. Nold, M. Haklay, and E. Kanjo. 2019. User experience of digital technologies in citizen science. *Journal of Science Communication* 18 (1):1. doi: 10.22323/2.18010501.

Skarlatidou, A., J. Wardlaw, M. Haklay, and T. Cheng. 2011. Understanding the influence of specific Web GIS attributes in the formation of non-experts' trust perceptions. *Advances in Cartography and GIScience* 1:219–38.

Tomio (Weninger), B. 2017. Cartographic visualisation of noise and aspects of public understanding of this information. In *Participatory sensing, opinions and collective awareness: Understanding complex systems*, ed. V. Loreto, M. Haklay, A. Hotho, V. D. P. Servedio, G. Stumme, J. Theunis, F. Tria, 181–98. Cham, Switzerland: Springer.

Trojan, J., S. Schade, R. Lemmens, and B. Frantál. 2019. Citizen science as a new approach in geography and beyond: Review and reflections. *Moravian Geographical Reports* 27 (4):254–64. doi: 10.2478/mgr-2019-0020.

Turner, A. J. 2006. *Introduction to neogeography*. Sebastopol, CA: O'Reilly.

United Nations. 2015. A/RES/70/1 UN General Assembly: Transforming our world. The 2030 Agenda for Sustainable Development. Seventieth session of the UN General Assembly, September 25.

United Nations Environment Agency. 2017. Global vision statement. Science-Policy Business Forum, Nairobi, Kenya, 3rd UN Environmental Assembly.

Wald, D., J. Longo, and A. R. Dobell. 2016. Design principles for engaging and retaining virtual citizen scientists. *Conservation Biology* 30 (3):562–70. doi: 10.1111/cobi.12627.

Wynne, B. 2006. Public engagement as a means of restoring public trust in science: Hitting the notes, but missing the music? *Community Genetics* 9 (3):211–20. doi: 10.1159/000092659.

ARTEMIS SKARLATIDOU is a Lecturer in Citizen Science in the Department of Geography at University College London, North West Wing, Gower Street, WC1E 6BT London, UK. E-mail: a.skarlatidou@ucl.ac.uk. Her research interests include sociotechnical perspectives and concerns that arise from the implementation of public participation approaches, including citizen science, to address social and environmental issues.

MARCOS MOREU is a Research Associate in the Department of Geography at University College London, North West Wing, Gower Street, WC1E 6BT London, UK. E-mail: marcos.moreu@ucl.ac.uk. His research interests include participatory mapping, scientific crowdsourcing, information and communication technology for development (ICT4D) and HCI.

MUKI HAKLAY is a Professor of Geographical Information Science in the Department of Geography at University College London, North West Wing, Gower Street, WC1E 6BT London, UK. E-mail: m.haklay@ucl.ac.uk. His research interests include participatory mapping, participatory and citizen science, and public access, use, and creation of environmental information.