How do Citizens Engage with Science. Challenges and Recommendations

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Recommended citation:

Bautista-Puig, Núria; **Orduña-Malea, Enrique** (2024). "How do citizens engage with science. Challenges and recommendations, v. 33, n. 6, e330601.

https://doi.org/10.3145/epi.2024.0601

Article received on August 23rd 2024
Approved on September 03rd 2024

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Abstract

Citizen science (CS) has become a crucial form of public participation in science, helping to address global challenges and contribute to more democratic knowledge production. Despite its increasing presence (including literature reviews), uncertainties persist regarding the quality of data collected, the level of citizen participation, and ethical concerns. This editorial explores CS participation, aiming to provide a comprehensive analysis of engagement patterns, and challenges, and offering recommendations to enhance citizen involvement in scientific initiatives. A systematic review of existing literature indexed on *Web of Science* is conducted, following the PRISMA framework. The review covered 1,613 selected studies examining 'participation' across various scientific fields, identifying the methodologies used and the factors influencing engagement, such as benefits, challenges, and ethical concerns. The results reveal a growing trend in CS, particularly in the natural sciences, with citizen involvement mostly limited to data collection rather than higher-level engagement like analysis or decision-making. The study also highlights the underrepresentation of social sciences and the need for more interdisciplinary approaches. In conclusion, the article calls for increased interdisciplinarity, greater integration of citizens in decision-making processes, diversification of participatory methods, and context-specific strategies for participation. It emphasizes the importance of fostering public trust and awareness in science and proposes that these actions will improve the inclusivity and impact of citizen science initiatives.

Keywords

Citizen Science, Literature Review, Public Participation in Science, Participatory Methods, Public Awareness in Science, Recommendations.

1. Citizen Science: Toward a New Framework for Participation

Science is moving towards new participatory ways of generating knowledge by integrating different perspectives and forms to better understand global challenges, improve decision-making, and strengthen democracies (**Monzón Alvarado *et al.***, 2020). Citizen science (CS) is one of the many forms of public participation in producing scientific knowledge, and citizens get involved in different ways through expertise, tools, or resources (**European Commission**, 2014). The benefits and potential application of CS in multiple areas of knowledge have been highlighted by the literature (**Conrad; Hilchey**, 2011; **Jordan Raddick *et al.***, 2013; **Sullivan *et al.***, 2014; **Tauginienė *et al.***, 2020), including the democratization of science, increased public participation (scientific literacy), the generation of new knowledge, the expansion of researchers' capabilities, and the increase in geographic reach, among others (**West; Pateman**, 2017; **Conrad; Hilchey**, 2011).

However, there is still uncertainty regarding other issues, such as the collection (and quality) of data, the different levels of citizen participation and their actual contribution to science, as well as ethical issues (e.g., invisibility of citizens) (**Ali *et al.***, 2019; **Conrad; Hilchey**, 2011; **Elliott; Rosenberg**, 2019; **Kullenberg; Kasperowski**, 2016). From the information (**Bautista-Puig *et al.***, 2019; **Kullenberg; Kasperowski**, 2016; **Pelacho *et al.***, 2021) and communication (**Sierra-Caballero**,

2022) perspectives, the CS literature has been analysed mainly from a top-down perspective. For example, how do scientific investigations include this type of research and its characteristics (e.g., topics)? However, a bottom-up perspective is also needed to better understand the mechanisms citizens use in scientific initiatives. Precisely, this editorial analyses CS participation and engagement to find research challenges and propose recommendations. By adopting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, the literature on CS is systematically examined to ensure transparency and replicability in identifying, screening, and selecting relevant studies.

> This study provides a comprehensive understanding of how and where citizens engage in scientific initiatives

The analysis spans key dimensions, including scientific areas, methodologies, and factors (e.g., benefits, drawbacks, etc.) influencing citizen involvement. This structured approach provides a comprehensive understanding of how and where citizens engage in scientific initiatives, highlighting the scope of their participation, new avenues of research, and potential strategies to enhance citizen involvement across diverse scientific fields. *Web of Science* (WoS) was used employing search keywords such as "citizen science," "participation," "engagement," and "public involvement".[1] Initial searches yielded 2,621 studies, which were then filtered through several phases. The first phase involved removing duplicates and screening abstracts to determine relevance based on predefined inclusion criteria. Only studies discussing citizen participation within formal scientific projects or analysing outcomes related to citizen involvement were selected.

In the final stage, 1,613 articles met all inclusion criteria and were included in the systematic review for a detailed qualitative and quantitative analysis (Figure 1). Data were extracted to evaluate topics and influencing factors across disciplines, providing insights into how public participation is addressed in citizen science initiatives. *ChatGPT 4.0* (*OpenAI*, 2024) was used to extract information from each article. The content was subsequently reviewed and edited manually. The information on methodologies used (e.g., community-based participatory research, surveys, interviews, etc.), participation/engagement information (e.g., benefits of participation or challenges), and the research area were analysed based on titles, abstract, and keywords information. Considering these metadata fields, each document was assigned to an area (e.g., Geography, Astronomy, Biology, etc.), allowing multiclass classification. These classifications were subsequently grouped into major areas.

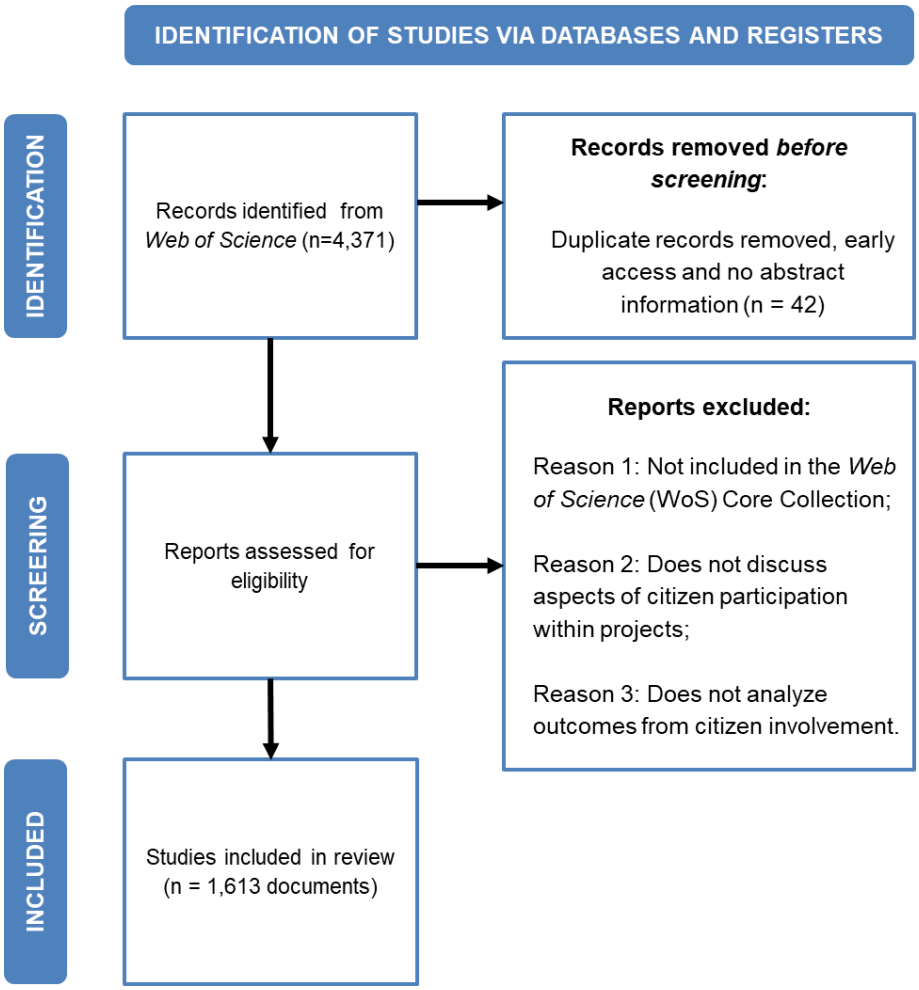


Figure 1: PRISMA Methodology Followed in this Study[2].

80% of the documents were assigned to Natural Sciences, 22% to Education, and 20% to Health Science. The remaining categories (Social Sciences, Humanities, Applied Science and Technology, and Communication and Information Sciences) represent roughly less than 5% each. Finally, 48 documents were not assigned to any area. Descriptive graphs were displayed by using R software (**R Core Team**, 2022). *CorTexT Manager* (**Cortext**, 2016) was employed for topic identification through lexical extraction of single and multi-term n-grams using Natural Language Processing (NLP) techniques. This software was used to obtain the frequency of keywords (frequency < 3 and 300 nodes) as well as to generate a Sankey diagram showing the evolution of topics. The authors further validated the labels obtained for each cluster.

2. Decoding the Evolution of Citizen Science: From Engagement to Action

Based on the data analysis, some patterns emerge regarding citizen participation in the reviewed texts.

2.1. Limited Level of Participation

> Ecological and environmental research areas are at the forefront of citizen science initiatives

A clear pattern shows that ecological and environmental research areas have been at the forefront of CS initiatives, with notable efforts and contributions (e.g., projects like *eBird*[3]). Figure 2 shows the evolution of the main areas.

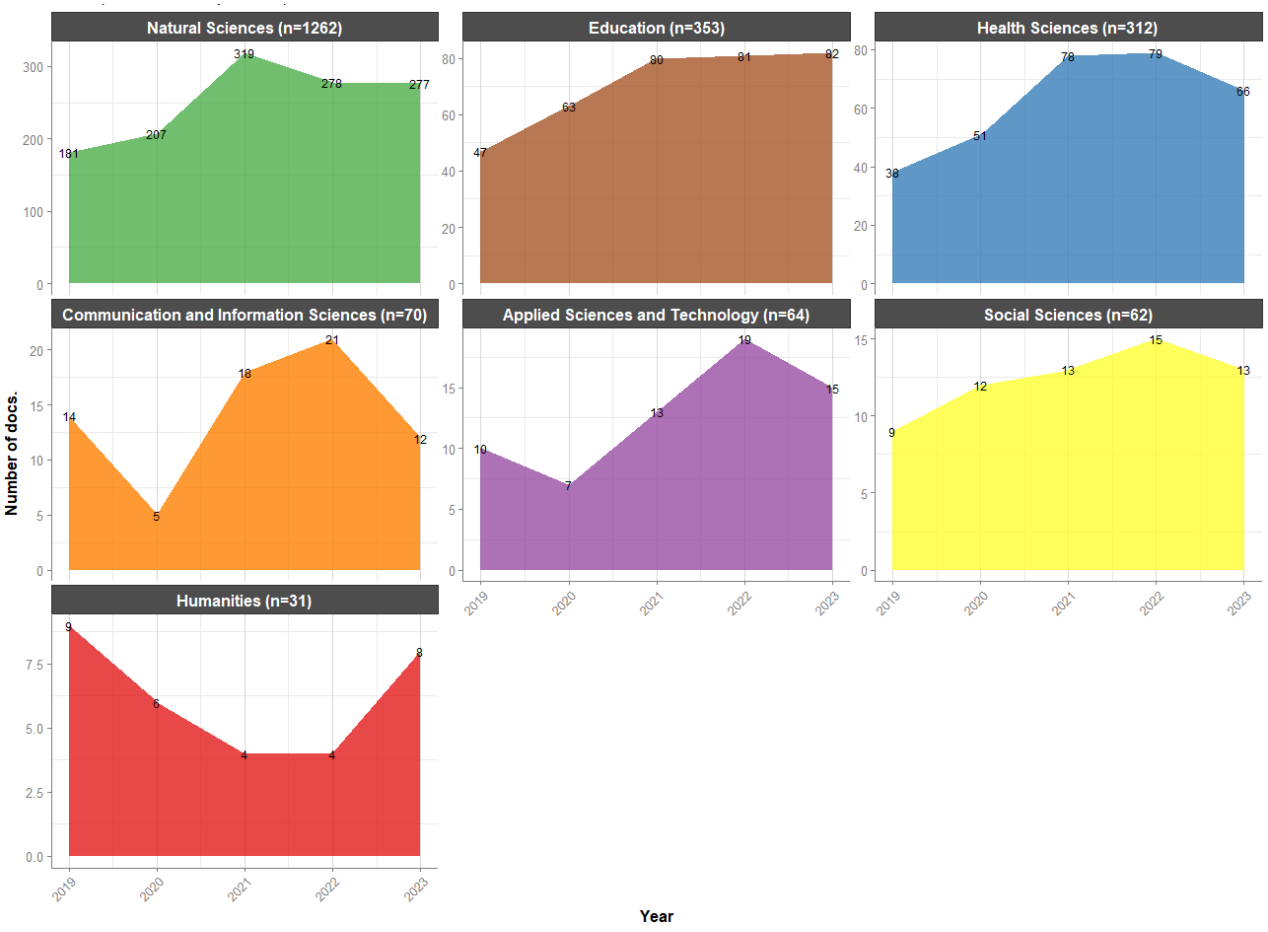


Figure 2: Number of Documents by Discipline.
Note: 2024 is excluded. Other disciplines (e.g., documents not assigned) are not included.

Natural Sciences lead the productivity ranking with 1,262 documents, showing a significant growth of 53% over the period. Education has also gained relevance (74.5% growth), becoming an emerging area. This increase is presumably related to the increasing emphasis on STEM education and the integration of participatory learning approaches and capacity-building efforts, which aim to actively engage students, enhance scientific literacy, and foster critical thinking skills. Health Sciences also present a growing trend (107.89% up to 2019), which could be attributed to the incorporation of participatory approaches in this field, as well as the challenges involved in scaling such initiatives across diverse healthcare settings. On the other hand, fields such as Social Sciences, Humanities, Communication, and Information Sciences have fewer documents, with notable fluctuations. This issue may be explained by the historically lower adoption of CS methodologies in these areas, as they rely on qualitative methods and theoretical frameworks that are

less aligned with the traditional data-driven approaches of CS. Nevertheless, their potential for interdisciplinarity projects is significant, as these fields can offer critical perspectives on cultural, ethical, and communicative aspects of participatory research. Despite this potential, interdisciplinary and transdisciplinary approaches remain underrepresented. For example, only 42 dataset documents include the term 'interdisciplinarity,' while 'transdisciplinary' approaches are mentioned 38 times.

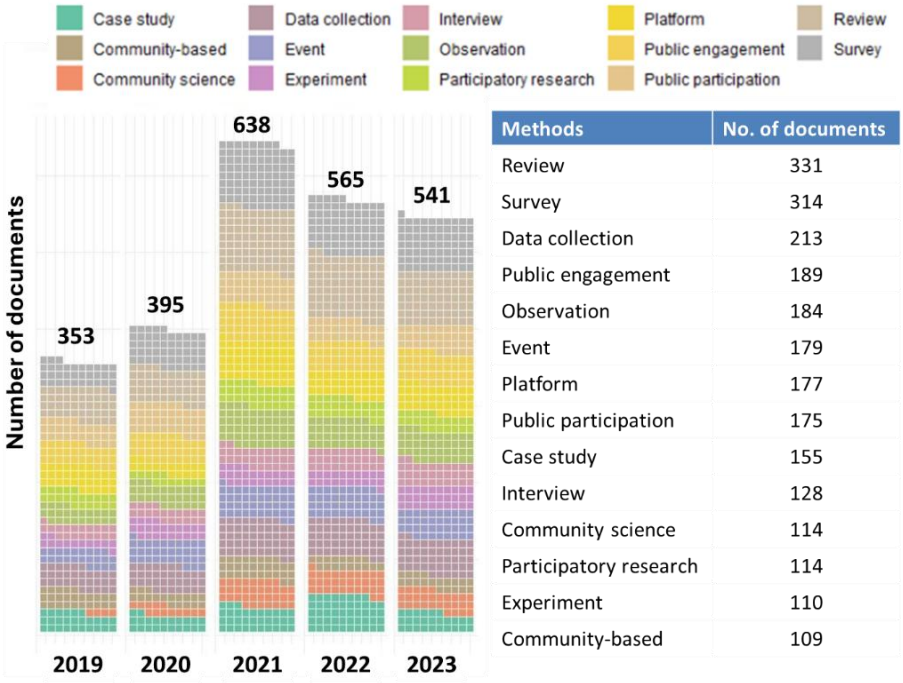
In terms of participation level, many studies highlight that citizen involvement is primarily focused on data collection activities at the initial stages of research, where citizens act as 'sensors' or 'data collectors'. Examples include citizen science initiatives that focus on monitoring biodiversity, such as tracking invasive species in ecological systems (e.g., **Cakmak *et al.*** (2021); **Khalighifar *et al.*** (2021)) or participating in public health studies by reporting symptoms or environmental exposures (**Wade *et al.***, 2023; **Caputo *et al.***, 2021). Technological tools (e.g., apps), surveys, and ecology and environmental-related methods often facilitate these activities. Participation as 'analysts' or 'decision-makers' (high level of involvement) appears less frequently, which suggests an underutilization of citizens' potential to contribute to deeper analytical processes or decision-making.

2.2. Limited Diversity in Participatory Methods

> Citizen involvement is primarily focused on data collection activities at the initial stages of research, where citizens act as 'sensors' or 'data collectors'

While participation occurs at different levels, the data reveals a heavy reliance on traditional participatory methods, such as surveys (314 documents), commonly used in community health projects and public opinion studies on air quality (e.g., **Samulowska *et al.*** (2021)) (Figure 3). While some traditional participatory methodologies appear frequently (e.g., action research with 24 articles; community-based with 113; community-based participatory research with 24), others are gaining traction but still remain underrepresented. For example, community science (118 articles) and crowdsourcing (91 articles) show a moderate presence, reflecting their potential for engaging large and diverse groups. On the other hand, innovative approaches such as co-creation (6), co-design (28), participatory design (14), and crowd science (2) are scarcely used, limiting the adoption of these novel methodologies.

Certain methods are closely linked to specific fields, suggesting a dependence on standard (familiar) methodologies. For example, mapping and monitoring are prevalent in Ecology and environmental projects, such as mapping invasive species (e.g., **Kalaentzis *et al.*** (2021)) or monitoring water quality (**Odetola *et al.***, 2021). This trend reflects the technical demands of these fields, where spatial and temporal data are critical. Otherwise, community workshops are frequently mentioned in Education and science communication projects, such as engaging students in STEM activities (**Dopico *et al.***, 2021). These workshops and education-based approaches are commonly used in initiatives focused on STEM engagement and public outreach.



Methods	No. of documents
Review	331
Survey	314
Data collection	213
Public engagement	189
Observation	184
Event	179
Platform	177
Public participation	175
Case study	155
Interview	128
Community science	114
Participatory research	114
Experiment	110
Community-based	109

Figure 3: Evolution of the Top 15 Methodologies (left) and Frequency (right).

Note: each square in the waffle graph represents 49,480 documents, and 2024 (n=46 docs.) is not included. 'Citizen Science' is not included as a methodology, as many projects are described as citizen science results

2.3. Benefits Outweigh Drawbacks in Citizen Science Initiatives

Many studies highlight the benefits and positive effects of CS. Key benefits include richer and more representative datasets (such as those seen in **Giannetti *et al.*** (2023)) and the ability to raise public awareness (**Soria *et al.***, 2021). Additionally, CS fosters trust and collaboration between the scientists and the communities (**Bogomolni *et al.***, 2021), and enhances public policy outcomes. For instance, **Manshur *et al.*** (2023) emphasize how citizen participation improves awareness of air pollution and its associated health risks while empowering communities with scientific tools to address local challenges and effectively advocate for policy changes with decision-makers. Intangible benefits, such as citizen empowerment, learning, or community cohesion, are less frequently addressed. For instance, **Montes *et al.*** (2022) highlight the empowerment of adolescents in a Colombian rural area using the *Our Voice Citizen Science Research Method*. However, CS drawbacks remain underexplored. For example, **Moczek *et al.*** (2021) point out that while participation rates are often emphasized, the overall level of knowledge among volunteers remains very low.

2.4. Influence of Cultural and Socio-economic Contexts on Participation Strategies

> Intangible benefits, such as citizen empowerment, learning, or community cohesion, are less frequently addressed by the literature

The influence of cultural and socio-economic contexts on participation strategies highlights the importance of tailoring these approaches to the specific characteristics of the target population. Cultural contexts implicitly shape how citizens engage in participatory initiatives. For example, participation tends to be collective and closely tied to addressing immediate local needs in rural communities (**Silva *et al.***, 2023; **Montes *et al.***, 2022). Conversely, urban settings often emphasize technological or policy-related issues, such as air quality monitoring (**Bo *et al.***, 2020) or urban planning (**Brom *et al.***, 2023). These differences underscore the necessity of adapting strategies to each context's unique socio-economic and cultural dynamics.

2.5. Challenges and Critical Perspectives on Participation

> Citizen participation often requires more inclusive and thoughtfully designed approaches to ensure meaningful engagement across diverse contexts

Participation is generally represented positively. However, some studies evidence challenges and critical perspectives, such as the limited representativeness of participants and lack of inclusiveness (**Cristóbal *et al.***, 2023), and limited participation involving citizens only at superficial levels, such as tokenistic data collection or data reliability (e.g., **Leocadio *et al.*** (2021)). Additionally, barriers to participation due to technological or socio-economic constraints are frequently noted. These examples suggest that, despite its many benefits, citizen participation often requires more inclusive and thoughtfully designed approaches to ensure meaningful engagement across diverse contexts.

3. The Shifting Landscape of Citizen Science Topics

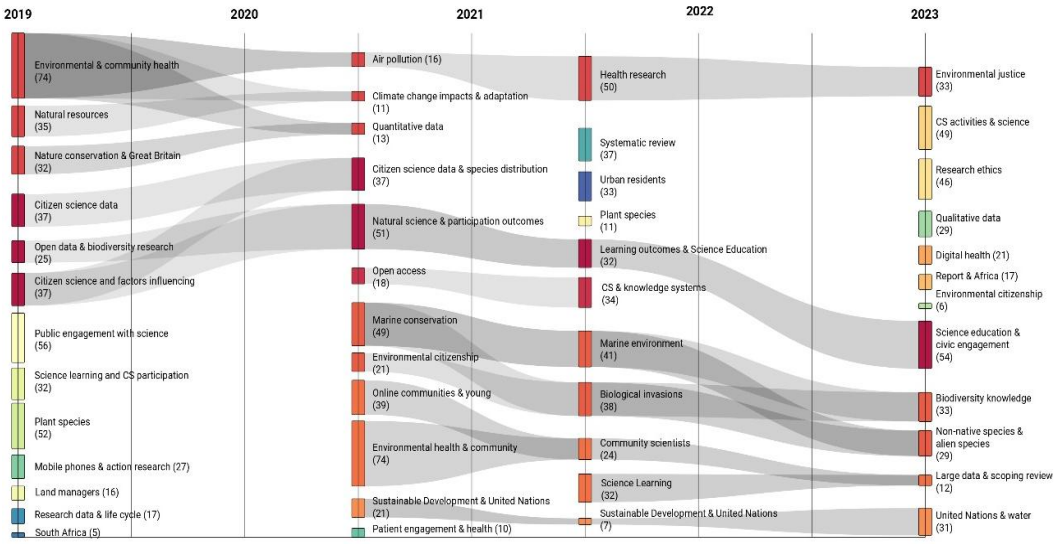


Figure 4: Sankey Diagram of the Evolution of Topics over Time (2019-2023).

Figure 4 includes the evolution of topics from 2019 to 2023 through a Sankey diagram. Not surprisingly, environmental projects dominated in the period (e.g., 'Nature conservation & Great Britain' in 2019; 'Climate change impacts &

adaptation' in mid-2020), leading even to the creation of 'Environmental citizenship' as a new specific citizen figure.[4] Health also emerges as a significant field (e.g., 'Patient engagement & Health' in mid-2020; 'Health research' in mid-2021). The impact of the COVID-19 pandemic is also reflected in topics like 'Online communities' in 2020. In contrast, areas such as social sciences do not appear to be represented in CS projects, pointing out a significant gap and a potential opportunity to foster interdisciplinary approaches and inclusivity in these areas. This underrepresentation may limit the scope of CS to primarily STEM-focused disciplines. Furthermore, it raises concerns for funding agencies and project coordinators about ensuring a more equitable distribution of disciplines and fostering stronger interdisciplinary collaboration. The transition of engagement topics from broader topics/methodologies to more specialized ones is also observed in Figure 4. For instance, topics such as 'Public Engagement with Science' and 'Citizen Science Participation' are prominent in the earlier years but evolve into more focused areas like 'Science Education & Civic Engagement' by 2023. This shift highlights the growing diversity of methodologies and underscores the importance of fostering meaningful public engagement in ways that align with specific research goals and priorities. Another noteworthy pattern is the rise of clusters related to open science. Topics like 'Open Access' in 2021 and 'Research Ethics' in 2023 align closely with the broader open science wave. Similarly, concerns about data are reflected in themes like 'Open data and biodiversity research' in 2019 and 'Large data' in 2023, underscoring the increasing emphasis on data accessibility (and quality) and their management in research.

4. Key Recommendations

Based on the analysis of the data and the identified patterns in CS projects, the following recommendations are proposed to enhance participation, innovation, and interdisciplinary collaboration in future initiatives.

1) Address Underrepresentation by Fostering Inter/Transdisciplinary Collaboration

The limited presence of social sciences in CS projects evidences the need for a more inter/transdisciplinary approach. Collaboration between STEM fields and social sciences/humanities can provide critical perspectives on societal issues, leading to more comprehensive and impactful research outcomes. The increasing complexity and interconnectivity of CS topics also call for sustained investment and strategic partnerships across disciplines. Funding agencies and project coordinators should prioritize interdisciplinary projects, which will be essential for addressing these gaps and maximizing the potential of CS.

2) Expand Participation Beyond Data Collectors

While data collection remains a starting point for citizen involvement, efforts should focus on integrating citizens into higher levels of participation, such as data analysis and decision-making. This approach would fully leverage their potential and foster deeper engagement, particularly in health sciences and environmental research. Additionally, developing theoretical frameworks to quantify and monitor participation (e.g., levels of engagement, diversity of participants, and impact on participants' skills or community outcomes) is crucial for assessing engagement, participation levels, and outcomes systematically. Such frameworks ensure consistency and reliability in measuring the impact of CS initiatives.

3) Diversify Participatory Methods

Reliance on traditional approaches (e.g., surveys) limits the depth and breadth of citizen involvement. Using blend traditional methods and incorporating more innovative methodologies and emerging tools (e.g., artificial intelligence) can broaden the scope of CS projects, fostering creativity and increasing the participation level.

4) Tailor Strategies to Socio-economic and Cultural Contexts

> Participation strategies should be adapted to the unique socio-economic and cultural dynamics of target populations

Participation strategies should be adapted to the unique socio-economic and cultural dynamics of target populations. For example, rural communities may benefit from collective, locally focused approaches, while urban populations might engage more effectively through technology-driven or policy-oriented initiatives.

5) Foster Public Awareness and Trust in Science

> Building trust between researchers and communities, is critical, which can be supported by transparency, ethical practices, and co-designed approaches

Enhancing public awareness about the benefits of CS, alongside building trust between researchers and communities, is critical. These efforts can be supported by transparency in process and outcomes, ethical practices, and co-design approaches that prioritize mutual respect, shared priorities, and community values. These insights suggest opportunities to enrich participatory projects by adopting more inclusive, innovative, and theoretically

grounded approaches. By addressing these gaps, researchers/project managers/funders can design projects that better leverage the potential of citizen participation across different thematic areas.

5. Notes

1. The query used is the following: TS= ("Citizen Science" OR "Community Science" OR "Participatory Science") AND ("Engagement" OR "Participation" OR "Commitment" OR "Involvement" OR "Public Participation")
2. Source: *https://www.prisma-statement.org/prisma-2020-flow-diagram*
3. *https://ebird.org*
4. 'Environmental Citizenship' is defined as the responsible pro-environmental behaviour of citizens who act and participate in society as agents of change in the private and public sphere, on a local, national, and global scale, through individual and collective actions, in the direction of solving contemporary environmental problems, preventing the creation of new environmental problems, achieving sustainability as well as developing a healthy relationship with nature (source: *https://www.cost.eu/environmental-citizenship*)

6. Financing

This work has been supported by a *Ramón y Cajal* grant funded by the *Spanish Ministry of Science* (Ref: RYC2022-037076-I), and by the *PRIME TIME* project (PID2022-142569NA-I00), funded by MCIN/AEI/10.13039/501100011033, and by "ERDF A way of making Europe".

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