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Citizen Science and Inequality: Participation, Access, and Benefits

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ABSTRACT

Citizen science has emerged as an important approach to expanding public participation in scientific knowledge production, enabling non-professionals to contribute to research activities across diverse disciplines. However, despite its potential to democratize science, citizen science initiatives may reproduce existing social inequalities by creating uneven patterns of participation, access, recognition, and distribution of benefits. This study examines the relationship between citizen science and inequality by exploring how social, economic, technological, and institutional factors influence participation and outcomes. It analyzes the conceptual foundations of citizen science, focusing on participation, accessibility, and equity through the lens of participatory justice. The study further investigates historical and sociodemographic patterns of engagement, barriers affecting marginalized communities, and the unequal distribution of scientific resources and benefits among different social groups. It reviews methodological approaches for assessing equity in citizen science, including comparative analysis of participation rates, access to scientific data, recognition of contributions, and decision-making influence. The paper also examines case studies across disciplines and highlights the role of policy frameworks, institutional practices, and inclusive strategies in promoting equitable citizen science. Findings suggest that while citizen science provides opportunities for scientific empowerment, community engagement, and knowledge democratization, deliberate efforts are required to address digital divides, structural barriers, and unequal access to scientific opportunities. Achieving truly inclusive citizen science requires policies and practices that prioritize openness, accessibility, recognition, and meaningful participation of diverse communities.

Keywords: Citizen Science; Inequality; Public Participation in Science; Scientific Equity; and Knowledge Accessibility.

INTRODUCTION

The Oxford English Dictionary defines citizen as "a legally recognized subject or national of a state or commonwealth, either native or naturalized" and, in its extended form, "an inhabitant of a particular town or city" [1]. The complementary concept of science is defined as "the state or fact of knowing [2]. So-called 'natural science' is now often treated as 'the basis' or 'the ground', an inchoate aspect of an early scientific outlook which, by the seventeenth century, increasingly tended toward a preoccupation with observation, experiment, mathematics and all forms of quantification"[2]. Insect collecting, like telescope-making or meteorology, became very popular in the seventeenth and eighteenth centuries among the different social classes and led to a form of civic-minded scientific endeavor [3]. The participation of citizens in science is at the heart of the definition of citizen science and concerns both its development in education, science, and museums and its evolution from non-electronic to electronic modes of communication [1]. Citizen science stimulates the interest of non-specialists in science and scientific facts and gives them the sense that they contribute to authentic scientific knowledge. The

digital divide and lack of access to information and communication technologies and infrastructures foster a situation where only privileged minorities of the population benefit from citizen science initiatives [2]. Such inequalitarian practices themes introduced by Pierre Bourdieu, are reminiscent of the work of Michel Foucault on the paradox of the electronic apparatus offering everyone access to culture and knowledge at the price of a deterioration of the public nature of knowledge both through privatization and through the inaccessibility of the educational materials necessary for understanding culture and knowledge in context [3]. The present article is dedicated to the analysis of the inequities, barriers, and benefits of citizen science as it is practiced in some twenty disciplinary case studies, of the methodologies developed to assess these aspects across disciplines, and of their consequences in terms of institutional policies of funding and organization [4].

Conceptual Framework: Citizen Science, Participation, and Inequality

Citizen science harnesses the unpaid volunteer labor of members of the public in the generation of new scientific knowledge. Recent evidence indicates that significant proportions of the population participate in citizen science projects [1]. Nevertheless, disparities persist in participation rates by age, education level, race, and location of residence [2]. The unequal distribution of citizen science participation may amplify existing social inequities in access to scientific knowledge, technical literacy, and opportunities to co-create the scientific record [1]. Past research on citizen science, however, has not systematically explored the unevenness of participation across social groups [3]. Equity is central to both the definition and practice of citizen science; for example, the 2016 European Citizen Science Association (ECSA) Declaration on Citizen Science Characterizes as "Citizen Science unequivocally" "based on the principles of reciprocity, inclusiveness of all sectors of society and the active engagement of citizens in the definition of societal challenges to be tackled[4]." An explicit focus on the social and socio-technical dimensions of citizen science enables a clearer assessment of differential engagement, access to data and other scientific outputs, and the distribution of associated benefits across diverse groups [3]. Following the parameters set by the ECSA Declaration, the empirical exploration of citizen science inequities is informed by theories of participatory justice that attend specifically to questions of recognition, access, and influence across the science-society interface [4].

Historical and Socio-demographic Patterns of Participation

Over the last two centuries, participation in citizen science has evolved considerably. The earliest documented projects occurred in the late 18th century, predating the term itself by almost two centuries, and involved the collection of meteorological data [2]. It is only by the mid-20th century, with the advent of the digital era, that significant growth resumed, driven primarily by government agencies and academic institutions [3]. The availability of the Internet and mobile technologies following the 1990s created new and broader opportunities for involvement, especially through worldwide platforms that continue to flourish today [2]. Contemporary participation patterns also bear the imprint of disciplinary tradition. Some fields embraced public engagement earlier, whereas others are relatively recent adherents [3]. The burgeoning field of health-related citizen science has not yet reached a critical mass of projects, making it more difficult to identify comprehensive participation patterns. Other disciplines, however, exhibit widespread activity that allows a robust exploration of historical trends and sociodemographic characteristics of participants [4]. Comparison of citizen science projects in astronomy, ecology, and environmental monitoring reveals substantial participation by either retired individuals or children two age demographics considered particularly suitable for involvement [5]. Around forty-five percent of contributors in astronomy are aged 25 to 34, and forty-five percent of contributors in ecology fall in the 35 to 44 range[6]. An early project in natural-history collections indicated that recordings primarily came from wealthier, English-speaking nations and that contributors were likely older than twenty-five within large-scale, multi-national projects, a similar pattern emerges [1].

Barriers to Participation

Citizen Science (CS) has gained momentum as a promising instrument for interdisciplinary knowledge production, including citizen participation in research activities [4]. This development has coincided with a growing literature on the degree of involvement of various equity-targeted population groups [5]. Broadly, participation has been uneven. Certain groups historically marginalized, economically disadvantaged, etc. Have not benefitted equally from the information, outcome, recognition, and opportunity that CS offers, and interventions to mitigate disparities have yet to be sufficiently explored [6]. Understanding the underlying societal dynamics is critical. Structural barriers (e.g. absence of public transport), institutional impediments (e.g. immediate participation exercised only in higher education segments), and individual constraints (e.g. insufficient time) constrain activities [3]. The CS landscape presents a rich tapestry of community inquiries, with groups that are primarily concerned with citizen participation in occupations, resources, health, and public safety able to share datasets across boundaries [3]. In most cases, these clusters intersect with major trends of social concern [7]. As a result,

participation in knowledge generation facilitates theoretical generalization about the locus of societal inequity and injustice. CS initiatives in the social realm increasingly feature either political elements that explicitly address existing disparities or the emergence of counter-networks that respond to undercurrents of coercive social interaction [1]. The uneven rate of diffusion of pertinent citizen-operator or operator-implemented platforms raises significant questions about relative access to datasets, exposure to knowledge generation, and competitive opportunity [2].

Beneficiaries and Impacts of Citizen Science

Citizen science benefits a wide range of groups and organizations, but socioeconomic status, education, age, gender, and ethnicity shape patterns of involvement and influence access to information, resources, and recognition [4]. All participants can gain such benefits as access to scientific data and outcomes, acknowledgment of contributions, and opportunities for capacity building [1]. The distribution of resources within citizen science projects is frequently uneven, reinforcing inequities evident across other social activities [2]. By systematically identifying those who receive benefits from citizen science, quantifying inequities with appropriate metrics, and investigating the relationship between the provision of benefits and equity-influencing factors, it is possible to assess whether the participatory nature of citizen science and the motivation to contribute to public knowledge promote social equity or perpetuate existing inequalities[2].

Methodological Approaches to Assess Equity in Citizen Science

Citizen science research should systematically compare participation, access, and benefits across social groups, quantify inequities with clear metrics, and situate findings within existing theory and policy implications [4]. Citizen Science encompasses a diverse range of approaches to public participation in scientific research and knowledge generation [5]. Participation is defined here broadly as involvement in citizen science projects what activities, how often, or for how long is not specified. Citizen Science is assumed to have positive social value because it promotes a closer relationship between science and society, offers pathways into science for non-specialists, and addresses pressing global challenges such as environmental degradation, biodiversity loss, and climate change [1]. Different groups experience differing levels of participation and enjoy unequal access to opportunities, recognition, and engagement in decision-making. There is widespread concern that such inequities could deepen existing societal divides, fuelling marginalization and discontent 4. An examination of equity as it relates to citizen Science, therefore, is justified [3].Citizen Science emerges from a history of science and technology studies (STS) and civic engagement. A civic epistemology framework is adopted that views citizen Science as public participation in scientific knowledge production citizens contribute to research through experimentation, observation, data collection, and analysis, generating information on a wide range of topics and issues, including environmental pollutants, urban access to grocery stores, and research integrity[4]. Participation in citizen Science is the focus of consideration; access, benefits, motivations, and learning opportunities are only considered later. Citizens are engaged as both producers and users of scientific information [5]. Citizen-science efforts often seek to include members of underrepresented groups, yet participation statistics across disciplines are rarely available and seldom analyzed from an equity perspective. Attention to participation patterns across social groups, therefore, is warranted [6].

Case Studies across Disciplines

Citizen science contains many cases and studies with participation, barriers, and benefits, although not always examined through the lenses of inequity and access [5]. The research engages case studies across different projects and disciplines to illustrate inequities, analyze barriers and mechanisms that shape citizen science participation and appreciation, and highlight similarity and variations in patterns and dimensions among the citizen science projects studied [1]. Comparing case studies across three disciplines offers insights on different project designs, scientific activities, and technologies, such as the analog or digital nature of tasks and the active research type versus data potential [5]. These comparisons help broaden understanding of citizen science practices and support the search for concrete methodological solutions to identified barriers and inequities [6].

Policy and Institutional Implications

Policies governing research data and citizen science have implications for equity by determining what data are collected, how they are used, and who benefits from them [6]. These policies shape the design of citizen science projects and influence the ability of participants to engage in the research process, access data, and realize the benefits of their involvement [5, 4]. Institutional practices further affect equity by defining what data are shared and how. Funding agencies in many fields require open-access publication of project results as a condition of research support; public availability of data is often not mandated, resulting in limited access to initial datasets and outputs [6]. Many data repositories require accession of the deposited data in acknowledgment of contributions; procedures governing such acknowledgments vary considerably across disciplines and projects, giving rise to

large discrepancies in equity [7]. Equity-oriented policy and institutional reforms address six interrelated dimensions: openness, model development, access, documentation, governance, and recognition [7]. Openness refers to both the data acquired by citizen science projects and the projects themselves, whereas project models establish installed capabilities and operational protocols that enable independent, ongoing activity and resource sharing. Access encompasses the availability of data collected through citizen science or underlying project workflows. Documentation specifies supplementary information such as project scope, expected contributions, and relevant tools that supports the design, deployment, and adaptation of citizen science initiatives [6]. Governance constitutes the formal and informal policies that shape data sharing, project uptake, and related modalities. Recognition involves the acknowledgment through citation, co-authorship, or other means that participants receive for their involvement, influencing further participation and the acquisition of project-related credits [7].

Strategies for Inclusive Practice

Citizen science has the potential to democratize knowledge and engagement in the scientific process, thus fostering equity across the socio-technical system; however, citizen science can also reproduce existing inequalities [4, 5]. Practices of citizen science range from data contribution through crowdsourcing to "extreme citizen science" and co-research in which the public participates fully in the research process [6]. Participatory research frames the current crisis of knowledge production, illustrating how expertise has become concentrated and hinders the participation of excluded groups [6]. Participatory research addresses this crisis by facilitating self-reflexive research that recognizes the political dimension of knowledge and fosters intellectual empowerment for the underrepresented [6].

Critical Reflections and Future Directions

Citizen science is now a priority for research and policy, offering a significant opportunity to engage people in science in ways that can benefit society broadly, but that risk deepening inequality [7]. Against the backdrop of a growing urgency to document this issue and address potential disparities, researchers are encouraged to produce a systematic assessment of the equity dimensions of citizen science through comparisons of participation, access, and benefits across social groups [6]. These elements can be defined and measured in ways that enable substantial insight into the nature, sources, and consequences of inequity, and facilitate hypothesis-driven research to interrogate the underpinnings of the observed phenomena. Selected theories of participatory justice, access, and empowerment framed a focus on citizen science scholarship to illuminate important knowledge gaps and motivate action toward the goal of equitable citizen science [6]. In citizen science and related enterprises, ensuring equitable engagement with the public and equitable benefit to different population groups remains a significant and inadequately addressed aspiration [7]. Citizen science and the associated umbrella terms of public participation in science and crowdsourcing have expanded rapidly within the last 20 years, launching a vibrant community. Broadly defined, citizen science encompasses the involvement of non-professionals in scientific research activities with a societal benefit component [7]. Citizen science initiatives began to flourish across many disciplines, a range of practical initiatives developed, and a growing body of literature on participation, governance, and scientific practice emerged. Despite these developments, systematic analysis of participation data has lagged, limiting understanding of who, how, and to what effect different social groups participate and the evolution of these patterns over time [5].

CONCLUSION

Citizen science represents a significant transformation in the relationship between science and society by creating opportunities for individuals and communities to participate in scientific research, generate knowledge, and contribute to solving social and environmental challenges. However, while citizen science has the potential to democratize scientific processes, this study demonstrates that participation and benefits are not distributed equally across social groups. Differences in socioeconomic status, education, geographic location, technological access, and institutional support continue to influence who participates, whose knowledge is recognized, and who benefits from citizen science initiatives. The analysis highlights that inequality in citizen science is shaped by both structural and individual barriers, including limited access to digital technologies, inadequate resources, lack of scientific literacy, time constraints, and exclusionary research practices. Although many projects seek to promote public engagement, they may unintentionally reinforce existing disparities when opportunities for participation, access to data, and recognition of contributions remain concentrated among privileged groups. Addressing these challenges requires a stronger commitment to equity-focused approaches in the design and implementation of citizen science projects. Inclusive strategies should prioritize accessibility, community involvement, capacity building, transparent governance, and meaningful recognition of participants' contributions. Policies governing research funding, data sharing, and institutional collaboration must also support equitable participation by ensuring that scientific knowledge and benefits are accessible to diverse communities. Future citizen science

initiatives should move beyond simply increasing participation numbers toward creating environments where all groups can actively influence research processes and outcomes. By integrating principles of participatory justice, openness, and social inclusion, citizen science can fulfill its promise as a tool for empowering communities, strengthening public trust in science, and advancing a more equitable system of knowledge production.

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