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Democratizing STEM: Citizen Science as a Tool for Engagement and Social Change

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ABSTRACT

Citizen Science offers a powerful approach to democratizing STEM education by making scientific inquiry more inclusive, accessible, and socially relevant. This paper explores how participatory research engages underrepresented students in real-world problem-solving, such as water conservation and environmental monitoring, fostering scientific identity, agency, and a sense of belonging. Case studies like Ponte Ahorrativo con el Agua highlight how Citizen Science supports AJEDI (anti-racism, justice, equity, diversity, and inclusion) principles and addresses systemic barriers in STEM. The paper argues that integrating Citizen Science into formal and informal education is key to creating equitable learning environments where all students can contribute to and benefit from scientific discovery.

Keywords: Citizen science, Inclusive education, Participatory research, STEM equity

INTRODUCTION

STEM education has long grappled with persistent inequities, particularly in the representation and participation of students from marginalized and underrepresented communities. Traditional science instruction often reinforces hierarchical models of knowledge transmission, positioning learners as passive recipients rather than active participants in the scientific process (Bonney *et al.*,

2016). This dynamic contributes to disengagement and limits students' sense of belonging in STEM fields.

Citizen Science—defined as a participatory approach that involves non-experts in scientific data collection and analysis—offers a promising alternative. By leveraging the lived experiences, observations, and contributions of diverse participants, Citizen Science democratizes scientific inquiry, promotes more inclusive educational practices (Campillo-Alhama *et al.*, 2024) and enhances motivation, promote global consciousness, and provide real-world learning experiences that are key to fostering a science-literate and sustainability-oriented society (Wu & Hsu, 2025). It not only fosters curiosity and motivation but also allows students to see themselves as agents of change, capable of addressing real-world problems through scientific methods.

Importantly, this approach holds transformative potential for equity in STEM. Research shows that students from historically excluded groups are more likely to persist in STEM when their learning is connected to social relevance and community impact (Ballard *et al.*, 2017). Citizen Science projects—such as those focused on water quality, biodiversity, and environmental justice—enable students to become co-creators of knowledge, strengthening both their scientific identities and career aspirations (Strand *et al.*, 2003).

This paper argues that Citizen Science can serve as a powerful tool for advancing equity and engagement in STEM education. To support this claim, it first outlines the theoretical foundations and educational benefits of participatory science. Next, it examines practical applications through real-world case studies, such as the *Ponte Ahorrativo con el Agua* project. Finally, the paper discusses existing challenges and offers recommendations for embedding Citizen Science more systematically into STEM learning environments. By doing so, it highlights how STEM education can evolve into a more inclusive, socially relevant endeavor.

The Role of Citizen Science in Advancing STEM Equity

Citizen Science is a participatory research approach that involves members of the public participating in scientific research, often collaborating with professional scientists (Kobori *et al.*, 2019). Unlike traditional research paradigms, which typically restrict knowledge production to academic institutions, Citizen Science fosters community-driven exploration, open collaboration, and real-world problem-solving (Jordan *et al.*, 2012). In urban planning, Citizen Science methods can facilitate public engagement in data gathering and knowledge co-creation, potentially leading to more collaborative decision-making processes (Cooper & Balakrishnan, 2013). Beyond scientific contributions, Citizen Science projects can also enhance participants' scientific literacy, interest in science, and civic engagement (Kobori *et al.*, 2019; Cooper & Balakrishnan, 2013). By involving

diverse participants in data collection, analysis, and dissemination, Citizen Science democratizes knowledge, making STEM more accessible and socially relevant.

A key contribution of Citizen Science is its alignment with AJEDI (anti-racism, justice, equity, diversity, and inclusion) principles, as it actively works to dismantle barriers to STEM participation (Cooper *et al.*, 2021). Traditional STEM education often reinforces systemic inequities by privileging students with access to high-quality resources, mentorship, and institutional support (Ballard *et al.*, 2017). Engaging children in eco- Citizen Science can promote environmental justice and inclusion while benefiting child development and fostering future environmental stewardship (Makuch & Aczel, 2020). Programs that involve marginalized groups in environmental monitoring, public health research, and technology-driven inquiry empower students to see themselves as essential contributors to scientific progress.

In this same vein, participatory research promotes a sense of ownership and belonging among students who might otherwise feel alienated from STEM disciplines (Strand *et al.*, 2003). Recent research has shown that self-efficacy and career interest significantly mediate the relationship between learning experiences and the intention to engage in citizen science, particularly among women, reinforcing the role of participatory science in building enduring scientific identities (Kao *et al.*, 2025).

Research indicates that engaging students in authentic scientific experiences and building strong peer communities can significantly enhance their scientific identity and motivation to pursue STEM careers. Studies show that community-based participatory research projects and peer-learning communities lead to increased researcher identity and STEM interest among high school students (Koo *et al.*, 2021). Similarly, undergraduate research opportunities, particularly those targeting underrepresented groups, improve academic self-concept and STEM identity (Betz *et al.*, 2021). Science communication skills, science identity, and science self-efficacy are found to be predictors of student motivation and behaviors in STEM community engagement (Murphy & Kelp, 2023).

The disconnect between scientific knowledge and students' lived experiences poses a significant challenge in STEM education. Research suggests that incorporating students' funds of knowledge and everyday experiences into STEM curricula can enhance engagement and understanding (Mejia & Wilson-Lopez, 2015). However, there is often a disparity between teachers' self-efficacy beliefs and actual implementation of interactive, hands-on learning in classrooms (Decoito & Myszkal, 2018). Scholars propose leveraging students' lived experiences alongside traditional literature reviews in STEM education research to address this issue, particularly for marginalized groups (Bufford *et al.*, 2022). Additionally, gender inequity in STEM can be tackled through strategies such as connecting STEM to girls' lives, supporting problem-solving, empowering girls to

overcome challenges, facing stereotypes, emphasizing collaboration, and providing diverse role models (Hughes *et al.*, 2020). These approaches aim to bridge the gap between formal STEM education and students' real-world experiences, potentially improving engagement and retention in STEM fields.

Case Studies: Citizen Science in Action

By intentionally designing for equity, Citizen Science initiatives can create more diverse and accessible opportunities, fostering positive identities in science among underrepresented communities (Hinojosa *et al.*, 2021). It offers an inclusive vision of science—one where all students, regardless of background, have the opportunity to contribute meaningfully to knowledge creation. Citizen Science initiatives have proven to be powerful tools for engaging underrepresented students in STEM by making scientific research relevant, participatory, and action-oriented. Research shows that participation in Citizen Science can strengthen students' sense of belonging in science, particularly for those with marginalized identities (Johns *et al.*, 2021). The following case studies illustrate how community-driven STEM projects have empowered students to develop scientific skills, strengthen their identities as contributors to science, and advocate for meaningful change.

In the first place, one compelling example is *Ponte Ahorrativo con el Agua* (Caballero Barragán & Gracia Hurtado, 2024), a school-based environmental education initiative in Nuestra Señora del Rosario school in Floridablanca, Colombia that engages ninth-grade students in monitoring water consumption at their homes. By counting and tracking litters of water consumed at each home, students intend to reduce gradually the unnecessary use of gray waters such as the one of the washing machines. This has an effect not only on saving water but also on saving money for their parents since these two items are correlated. Another notable example is a project where students from low-income neighborhoods used portable air quality monitors to track particulate matter (PM2.5), nitrogen dioxide (NO_2), and carbon monoxide (CO) levels around their schools and homes (Ottinger, 2016). By mapping pollution hotspots and correlating data with health disparities, students gained hands-on experience in environmental science and data analysis, as well as exposure to careers in public health, urban planning, and advocacy.

A third impactful Citizen Science model involves student-led biodiversity tracking projects that contribute to global conservation efforts. In resource-limited schools, students engage in field observations, using mobile apps such as iNaturalist and eBird to document local flora and fauna. Their contributions feed into scientific databases used by conservationists to monitor species distribution and habitat changes (Ballard *et al.*, 2017). Emerging research emphasizes that engaging children in environmental Citizen Science requires attention to

project purpose, supervision, and cognitive development. Yet, stakeholders widely affirm that children can meaningfully contribute to data collection and benefit from diverse educational, social, and career-related outcomes (Wilson *et al.*, 2025). Beyond technical learning, these initiatives foster environmental stewardship, critical thinking, and community leadership. Students not only apply scientific methods to real-world problems but also present their findings to policymakers, increasing their sense of agency in environmental decision-making. This model demonstrates how integrating STEM with social impact enhances student engagement, particularly in regions where environmental issues directly affect daily life.

DISCUSSION AND CONCLUSIONS

To conclude, Citizen Science offers a transformative approach to making STEM education more equitable, participatory, and socially engaged. This paper has argued that by involving students—especially those from historically marginalized communities—in authentic research experiences, Citizen Science cultivates a stronger sense of identity within STEM fields and deepens engagement through real-world relevance. It challenges the traditional hierarchy of knowledge production and instead promotes collaborative inquiry, allowing learners to become co-creators of knowledge. The *Ponte Ahorrativo con el Agua* initiative serves as a case in point, illustrating how community-based participatory research can connect science education to environmental action and civic empowerment.

To harness this potential, it is essential that educators, institutions, and policymakers integrate Citizen Science into formal and informal learning spaces. This involves ensuring access to resources, mentorship, and culturally responsive pedagogies that recognize and uplift students' diverse backgrounds and lived experiences. By embedding these values into STEM practice, we can create educational ecosystems that are inclusive, justice-oriented, and action-driven.

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