



Mapping Citizen Science in Primary Education: A Systematic Review of Program Typologies, Learning Outcomes, and Implementation Success Factors

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Abstract

Citizen science (CS) programs in primary education have grown substantially as an innovative approach that embeds authentic scientific inquiry into formal learning. However, systematic reviews that examine program typologies, learning outcomes, and the conditions that determine successful implementation particularly at the elementary school level are still very rare. This review classifies program typologies, maps reported learning outcomes, and identifies the key enablers and barriers to CS implementation in primary education. The study applies a systematic review methodology drawing on 18 empirical studies published between 2019 and 2025, indexed in Scopus, and focused on elementary school students aged 5 to 12, selected via the PRISMA 2020 protocol. Findings show that the contributory typology predominates (n = 8; 44%), followed by collaborative (n = 6; 33%), co-created (n = 2; 11%), and hybrid designs (n = 2; 11%). Reported learning outcomes include gains in science content knowledge, inquiry and data analysis skills, environmental awareness, and motivation. Six primary success factors were identified: iterative and structured scaffolding, trained scientist–community partnerships, digital technology integration, place-based approaches, teacher support materials, and family engagement. CS in primary education generates multidimensional learning effects, but success depends heavily on pedagogical design quality, teacher competence, and the depth of community involvement. For curriculum developers and teacher educators, the review supports prioritizing collaborative or co-created designs over purely contributory ones wherever feasible, paired with structured scaffolding; for policymakers, it identifies standardized-testing pressure as a documented barrier that protected planning time can offset; for citizen science practitioners, it points to a concrete training need, namely facilitation skills that go beyond subject-matter expertise. Future research should explore CS implementation across diverse cultural contexts, particularly in developing countries.

Keywords: Citizen science; primary education; learning outcomes

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INTRODUCTION

Citizen science (CS) refers to collaborative research in which members of the public work alongside professional scientists to address real-world problems (Irwin, 2002). Two current policy pressures explain why this matters for primary education specifically, rather than education in general. The first is Education for Sustainable Development (ESD),

which asks schools to embed real environmental problem-solving instead of abstract content (Rodríguez-loinaz, 2026). The second is the broader STEM education agenda, which calls for interdisciplinary, authentic inquiry starting in the earliest grades rather than being deferred to secondary school (Ortiz-Revilla et al., 2022). CS offers a concrete mechanism for both agendas: an authentic, inquiry-based, and impact-oriented learning to model that conventional laboratory approaches struggle to replicate (Bonney, et al., 2009; Shirk et al., 2012). Rather than simulating science, CS places students in contact with genuine scientific processes, namely formulating research questions, collecting field data, analyzing results, and disseminating findings alongside researchers and community members (Ballard et al., 2017; Phillips et al., 2019).

Elementary school students bring high levels of curiosity and represent a formative window for the development of scientific dispositions, including scientific identity, environmental affinity, and critical thinking habits (Kelemen-Finan et al., 2018). Research suggests that early science experiences shape later STEM career choices and adult participation in scientific communities (Jordan et al., 2011). The integration of CS programs on the elementary level therefore carries implications well beyond short-term cognitive gains, as the development of habits of mind and long-term attitudes toward inquiry may prove far more consequential. Three primary participation typologies structure the CS literature. Contributory programs engage participants in data collection; collaborative programs extend involvement to data analysis and scientific discussion; and co-created programs involve participants across all phases of the research process (Bonney et al., 2014; Shirk et al., 2012). Wiggins & Crowston, (2011) Propose a goal-based typology encompassing action, conservation, investigation, virtual, and education categories. In formal educational settings, these distinctions are not merely taxonomic, as each typology carries distinct pedagogical implications for how deeply students develop scientific competence and come to see themselves as practitioners of science.

Despite a growing body of research on CS in education (Aristeidou & Herodotou, 2020; Roche et al., 2020; Würschum et al., 2019), focused syntheses that simultaneously address typology, learning outcomes, and implementation success factors on the elementary level remain limited. The most directly comparable prior work, Aristeidou & Herodotou, (2020), synthesized the effects of online CS on learning and scientific literacy across all education levels combined, from primary through university, without isolating elementary-specific findings or examining implementation success factors at all. Reviews with a narrower age focus have tended to address learning outcomes in isolation, without systematically classifying program typology or extracting the enabling and constraining conditions reported across the primary studies. To our knowledge, no existing review integrates all three components, typology, outcomes, and implementation conditions, specifically within the elementary band. Additionally, most studies originate from North American and European settings, leaving questions of cross-cultural transferability unresolved

This systematic review makes two contributions to the literature on citizen science in elementary education. Empirically, this study is one of the few reviews that simultaneously integrates typological classification, mapping of outcomes, and factors contributing to successful implementation specifically within the context of elementary education, thereby producing a structured analytical framework that can be directly applied to future program design and research. Theoretically, it extends situated learning theory, specifically the legitimate peripheral participation construct, from its original workplace and community settings to the classroom-based CS context, by showing how program typology structures the trajectory from peripheral data-collector to full participant in a scientific community of practice. This systematic review addresses three research

questions: first, what typologies of CS programs have been implemented in primary education in the recent empirical literature; second, what learning outcomes are consistently reported from elementary students' participation in CS programs; and third, what factors enable or constrain the successful implementation of CS programs in primary education. By addressing these questions together, the review aims to provide both theoretical contributions and actionable guidance for researchers, educators, and CS program designers.

METHODS

This study followed the PRISMA 2020 guidelines for systematic review reporting. The stages of the PRISMA framework include identification, screening, eligibility assessment, and inclusion (Page et al., 2021). The following are the detailed stages of the PRISMA used in this study:

Identification

Literature was retrieved from the Scopus database (<https://www.scopus.com/>), selected for its strong quality controls and international coverage (Liang et al., 2025). The search query was: ("citizen science" OR "public participation" OR "community science" OR "crowdsourcing") AND ("primary education" OR "elementary education" OR "school") AND ("engagement" OR "involvement" OR "participation" OR "learning") AND ("curriculum" OR "teaching" OR "instruction" OR "pedagogy") AND ("data collection" OR "research" OR "observation" OR "experimentation").

Screening

The screening phase is an initial selection process that involves reviewing the titles and abstracts of selected research articles. The purpose of this step is to efficiently identify the key points of the articles, including their objectives, methods, results, conclusions, and contributions, before determining whether they meet the inclusion criteria for in-depth analysis.

Eligibility

Data were extracted using a structured form capturing study identity (author, year, country), methodological design, participant characteristics, CS program features, typology classification, key findings, and researcher recommendations. CS typologies were categorized according to (Bonney, et al., 2009; Shirk et al., 2012; Wiggins & Crowston, 2011). Learning outcomes were assessed using the Phillips et al., (2018) framework, which distinguishes cognitive, affective, behavioral, and social domains. Success factors and barriers were analyzed through inductive thematic analysis.

Table 1. Eligibility Criteria

Criteria	Inclusion	Exclusion
Publication type	Article	Thesis, dissertation, conference, book chapter other
Publication year	2019-2025	Before 2019
Database	Scopus	Non scopus

Criteria	Inclusion	Exclusion
Research area	Citizen science	Other
Participants	Primary/elementary school students, ages 5–12 (Grades 1–6)	Other
Language	English	Non-english

Inclusion

Full-text reading of eligible articles confirmed final inclusion. Studies meeting all criteria were retained for synthesis. The PRISMA flow diagram (Figure 1) illustrates the complete selection process, from an initial pool of 153 records down to 18 included studies.

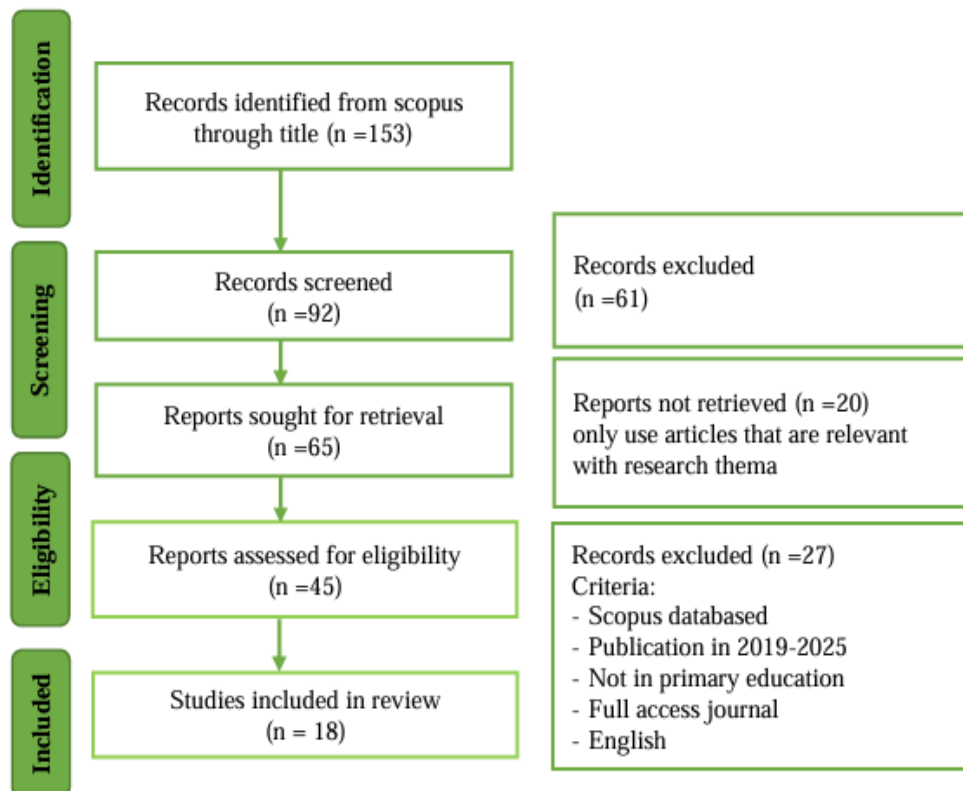


Figure 1. PRISMA Protocol

RESULTS & DISCUSSION

Results

The review identified 18 articles meeting all eligibility criteria, published between 2019 and 2025. Sixteen studies (89%) appeared between 2021 and 2025, a concentration that likely reflects the acceleration of CS research following the COVID-19 pandemic. Publication distributions are shown in Figure 2.

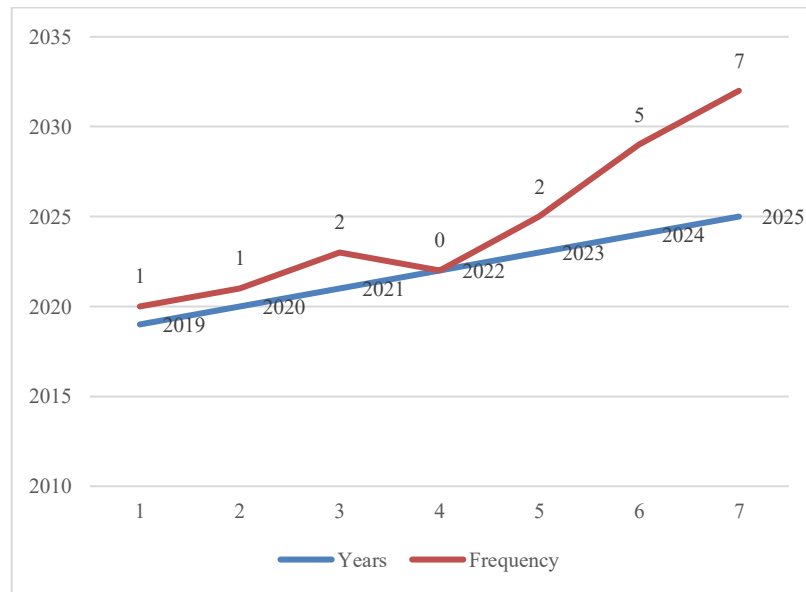


Figure 2. Trend of Publication by Years

Figure 2 shows that the publication trend shows a clear upward trajectory, particularly post-pandemic, with 2025 as the most productive year ($n=7$, 41%). Data from 2026 were excluded because the year was incomplete at the time of analysis.

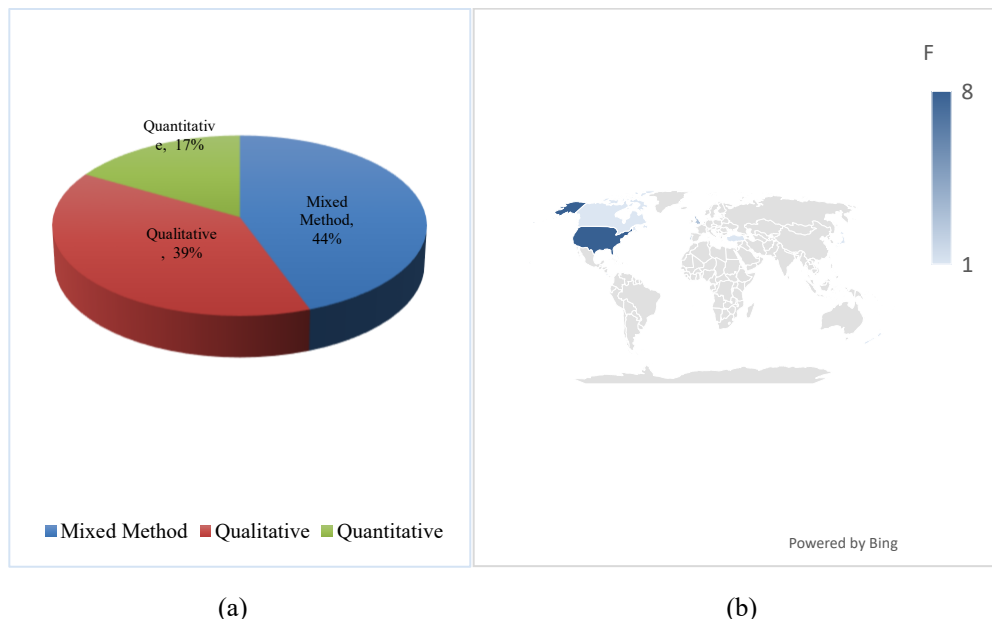


Figure 3. (a) Trend of Publication by Research Method, (b) Trend of Publication by Country

Figure 3 shows the distribution of research methodologies employed in CS studies at the elementary school level. Of the 18 included studies, eight (44%) adopted a mixed-methods approach, seven (39%) employed purely qualitative designs encompassing design-based research, ethnography, and case study, and three (17%) utilized quantitative designs, specifically pre- and post-test comparisons. Analysis of the included articles further revealed considerable variation in participant sample sizes, ranging from as few as

10 students (Bird et al., 2023) to as many as 290 children (Colucci-Gray et al., 2025), a pattern reflective of the scale heterogeneity characteristic of this field. Program duration similarly varied, spanning from five weeks to multiple academic years, with the majority of programs falling within a range of six weeks to one full academic year.

Figure 3 (b) shows the geographic distribution of the included studies. The United States produced the highest number of publications ($n = 8$; 44%), followed by the United Kingdom ($n = 3$), Portugal ($n = 2$), and single studies from Turkey, New Zealand, Japan, Canada, and Costa Rica. CS research in primary schools thus remains heavily concentrated in North America and Europe, while Asia and Africa are strikingly underrepresented. Southeast Asia and Indonesia in particular, regions characterized by extraordinary biodiversity and primary education systems currently undergoing significant reform, have yet to appear in Scopus-indexed CS research at the primary school level. This absence represents both a substantive research gap and a significant opportunity for future inquiry.

RQ1: Program Typologies and CS Project Types

The contributory typology was the most prevalent in this corpus ($n = 8$; 44%). In these programs, professional scientists design the research framework and students contribute primarily as data collectors. The seven programs documented under this typology are presented in Table 2.

Table 2. Contributory Typology: Programs and Applications

No.	Program	Author
1.	iNaturalist	Boaventura et al., (2021); Neves et al., (2024)
2.	Lost Ladybug Project	Carrier et al., (2024)
3.	CoCoRaHS	Carrier et al., (2025)
4.	PlantNet	Coşkunserçe, (2024)
5.	MammalWeb	Mason et al., (2025)
6.	Aula Verde	Bolt et al., (2024)
7.	I am an air quality scientist	Varaden et al., (2021)

Table 2 presents CS research in primary education that employs a contributory typology. Research conducted by Coşkunserçe, (2024), which utilized a contributory typology and the PlantNet app, was found to significantly enhance students' knowledge of plant species and foster environmentally conscious behavior regarding biodiversity. In line with this research, Varaden et al., (2021) reported that 258 elementary school students in London who participated in a CS program using portable air quality sensors experienced an increase in knowledge regarding pollutants and also exhibited positive behavioral changes in their commutes to school through the use of environmentally friendly modes of transportation. These research findings confirm that even the contributory typology, when implemented effectively, can yield meaningful learning if designed with appropriate scaffolding. Six studies (33%) employed the collaborative typology, in which students not only collect data but participate in analysis and scientific discussion with professional researchers. Table 3 presents these studies.

Table 3. Collaborative Typology: Programs and Applications

No.	Program	Author
1.	Project Noah	Zydney et al., (2021), Zydney et al., (2025)
2.	iNaturalist	Neves et al., (2024)
3.	Planet Hunters/Marine Metre Squared	Bunnting et al., (2025)

No.	Program	Author
4.	iSpot/SENSE Project	Colucci-Gray et al., (2025)
5.	STEAM Project	Sayuda et al., (2025)

Table 3 presents several CS studies conducted in elementary school settings that employ a collaborative typology. Zydney et al., (2025) Applied social network analysis (SNA) to identify unexpected data points, specifically student-initiated anomalous observations, that generated more scientifically substantive and in-depth discussions than the structured questions posed by teachers. The study also revealed complex role dynamics: scientists played an important part in guiding substantive discourse, yet when they provided overly direct answers, students became less inclined to ask questions independently. The researchers termed this phenomenon the “expert paradox” in school-based CS programs.

Two studies (11%) described CS programs operating at the co-created level, a typology in which students participate in most or all stages of the scientific process. Kermish-Allen et al., (2019) evaluated the WeatherBlur program in the Maine island communities, USA, involving 71 K–5 students, 11 teachers, 12 scientists, and 6 fishermen within a genuinely non-hierarchical learning network. Their SNA findings indicated that unstructured cross-role and cross-age interactions, deliberately free from hierarchical organization, produced stronger student understanding of earth science and greater skill in interpreting scientific graphs.

Comparable findings were reported by Sayuda et al., (2025), who examined a nine-week STEAM program focused on microplastics in Japan. The program adopted a co-design approach in which elementary school students aged 9 to 10, along with their parents and teachers, jointly developed environmental monitoring tools and creative projects. The initiative produced measurable gains in long-term student engagement and environmental awareness, with family involvement identified as the primary catalytic factor. Two studies (11%) implemented typologies that do not map neatly onto the three classic categories. Race et al., (2025) applied the Youth-focused Community and Citizen Science (YCCS) model, designed specifically for young learners, which positions students as “knowledge co-creators” with genuine agency in local resource management. Simms et al., (2024) Documented a programmatic evolution from a contributory to a collaborative design, achieved through iterative design-based research, a progression they termed a “developmental typology”.

RQ2: Learning Outcomes of Citizen Science in Primary Education

Analysis of the 18 studies identified six categories of learning outcomes, organized according to the Phillips et al. (2018) framework. Table 4 presents these categories with supporting evidence.

Table 4. Categories of Learning Outcomes in Elementary CS Programs

No.	Learning Outcome	Supporting Studies
1.	Science content knowledge	7 studies (Coşkunserçe, 2024; Mason, 2025; Boaventura, 2021; Neves, 2024; Kermish-Allen, 2019; Bolt, 2024; Yan, 2023)
2.	Inquiry and data skills	5 studies (Race, 2025; Bird, 2023; Zydney, 2025; Neves, 2024; Kermish-Allen, 2019)
3.	Science identity and agency	4 studies (Race, 2025; Simms, 2024; Kermish-Allen, 2019; Bird, 2023)
4.	Environmental awareness and literacy	6 studies (Yan, 2023; Varaden, 2021; Boaventura, 2021; Neves, 2024; Sayuda, 2025; Bolt, 2024)

No.	Learning Outcome	Supporting Studies
5.	Motivation and sustained engagement	5 studies (Carrier, 2024; Carrier, 2025; Sayuda, 2025; Colucci-Gray, 2025; Mason, 2025)
6.	Scientific data quality	2 studies (Neves, 2024; Kermish-Allen, 2019)

Science content knowledge was the most consistently reported outcome across 7 studies. Gains were most robust in biodiversity (Bolt et al., 2024; Coşkunserçe, 2024; Mason et al., 2025), coastal ecology and climate change (Boaventura et al., 2021; Neves et al., 2025), and socio-ecological systems (Yan et al., 2023). Particularly notable was the Neves et al., (2025) study, in which 126 fourth-grade students in Portugal generated data validated at 79.3% scientific accuracy, confirming that elementary students are capable of producing contributions of genuine research value.

Inquiry and data analysis skills appeared in 5 studies. Race et al., (2025) found that structured, iterative scaffolding significantly increased environmental science agency (ESA) and science identity in third- and fourth-graders. Bird et al. (2023), working with just 10 students, documented a rare instance of elementary students using eBird data to make consequential environmental decisions about their own school grounds, treating science as a genuine problem-solving tool rather than a curricular exercise. Science identity and agency were the most conditional outcomes in the dataset. Simms et al., (2024) Explicitly cautioned that participation in CS does not automatically develop science identity or understanding of the Nature of Science, as both require deliberate instructional attention. This finding challenges the assumption that engaging in scientific activities is, by itself, sufficient to produce reflective young scientists.

RQ3: Implementation Success Factors and Barriers

Thematic analysis of the 18 studies identified 11 enabling factors and 2 barriers, organized by level of influence in Table 5.

Table 5. Success Factors and Barriers to CS Implementation in Primary education

Level	Factor	References
Program design	Iterative, structured scaffolding	Race (2025); Bunting (2025)
Program design	Scientist–community partnerships	Zydney (2021, 2025)
Program design	Technology and digital tools	Coşkunserçe (2024); Varaden (2021); Kermish-Allen (2019)
Program design	Place-based approaches	Bird (2023); Yan (2023); Bolt (2024)
Teacher level	Educative support materials	Carrier (2024, 2025)
Teacher level	Professional training and autonomy	Mason (2025); Carrier (2024)
Student level	Personal values and identity	Bird (2023)
Student level	Explicit NOS instruction	Simms (2024)
Community level	Family and partner involvement	Sayuda (2025)
Barrier	Standardized testing pressure	Carrier (2024)
Barrier	Counterproductive scientist roles	Zydney (2025)

Iterative, structured scaffolding emerged as the most consistently cited success factor (Bunting et al., 2025). What matters here is not procedural instruction alone, but repeated cycles of data analysis experience, community feedback, and opportunities to present findings to genuine audiences. Race et al., (2025) Found that without repetition and meaningful public sharing, student science agency did not develop to its full potential, a finding with direct implications for program duration and design. Effective scientist–community partnerships required scientists with at least a foundational pedagogical

understanding. Zydney et al., (2021) Recommended training scientists specifically in discussion moderation and inquiry facilitation skills. Kermish-Allen et al., (2019) Demonstrated that non-hierarchical interactions among students, teachers, scientists, and community members, in their case including fishermen, produced richer learning networks than any unidirectional expert-to-student model.

Discussion

The dominance of the contributory typology (44%) aligns with global trends documented in the broader CS literature. This prevalence reflects practical realities: contributory programs integrate more readily into crowded curricula, demand less intensive teacher preparation, and rely on more mature digital infrastructure (iNaturalist, eBird, PlantNet). From a scientific data-supply perspective, the involvement of elementary students in contributory projects has produced data of validated scientific quality (Neves et al., 2025). That said, the contributory model carries inherent limitations when the educational goal extends beyond knowledge acquisition toward science identity and epistemic agency. Atias et al., (2023) State that participation in data collection does not automatically generate understanding of how science operates as a knowledge system (NOS). This implies a need to shift the design orientation from the citizen as data instrument toward citizen as scientific agent (Johns et al., 2021) at minimum, in the learning-critical phases of a program.

The co-created typology, still underrepresented in the elementary CS literature, shows the strongest potential for developing holistic scientific competence (Sardo et al., 2025). This supports the argument Aguirre et al., (2024) about the transformative potential of CS that appears fully realized only when participants engage across all stages of the research process. Greater investment in co-created program design and research for the elementary level is warranted. The review offers reasonably strong evidence that CS programs in primary education produce positive effects on science content knowledge and environmental awareness, consistent with prior meta-analyses (Aristeidou & Herodotou, 2020; Finger et al., 2023). Several important gaps remain, however. Most studies lack experimental designs with control groups, which means causal claims about CS participation and learning outcomes cannot be made with confidence. Rodríguez-loinaz, (2026) Found that only a small fraction of CS studies in compulsory education employed adequate experimental designs to support causal inference.

The temporal scope of measurement is also narrow. Most studies measured outcomes within a single programed cycle; longitudinal follow-up is rare. Sayuda et al., (2025) represents a partial exception with a nine-week program and post-program assessment, but this remains insufficient for understanding lasting effects. Perhaps most critically, no study in this corpus examined whether CS effects differ systematically by gender, socioeconomic status, or second-language learner status a significant gap given that equity and inclusion are foundational commitments in the CS field (Cooper et al., 2021; Johns et al., 2021; Smith et al., 2021). The six success factors identified in this review iterative scaffolding, trained scientist–community partnerships, digital technology, place-based design, teacher support, and family involvement can be visualized as a layered system. The innermost layer is program design that positions students as agents rather than data contributors. This is surrounded by a pedagogical support layer (scaffolding, teacher materials) and maintained by an ecosystem layer (partnerships, technology, community). Where any layer is weak or absent, the educational value of even a technically well-designed CS program is at risk.

The barrier posed by standardized testing pressure was documented particularly clearly by Carrier et al. (2024), who found that teachers' perceptions of curriculum priorities directly constrained implementation depth and that this effect was most pronounced in low-income schools, which stand to gain most from authentic science learning experiences. This points to a structural tension in which CS is most needed precisely where systemic pressures make it hardest to implement. The “expert paradox” identified by Zydney et al., (2025), in which scientists suppress student inquiry by providing answers too directly, represents an important original contribution to the field. It implies that programs should include orientation and training for participating scientists, not only for teachers. An effective scientist in the elementary CS context is not simply a subject matter expert; they must also be a skilled facilitator of children's inquiry, attentive to cognitive development and willing to support student-led discovery rather than replace it.

CONCLUSION

This SLR yielded 18 empirical studies on citizen science programs in primary education, revealing three main findings. First, the contributory typology dominates the implementation of CS in primary education globally, although the strongest evidence for the development of students' scientific identity and epistemic agency was found in the collaborative and co-created typologies. Second, CS programs in primary education produce multidimensional learning outcomes, including improvements in science content knowledge, inquiry skills, environmental awareness, and learning motivation. Third, the success of CS programs in primary education is highly dependent on the quality of pedagogical design, particularly repeated scaffolding, teacher competence and support, and the depth of community engagement and partnerships with trained scientists.

The practical implications of these findings are threefold. First, designers of CS programs in primary education need to move beyond the contributory typology and incorporate collaborative or co-created components to optimize the development of students' science identity. Second, teachers require robust supporting materials, ongoing professional training, and sufficient autonomy to adapt CS programs to their specific classroom contexts. Third, scientists involved in school-based CS programs need foundational pedagogical training, particularly in facilitating inquiry-based discussions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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