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From data to belonging: citizen science, urban friction, and institutional response in Siena

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ABSTRACT

This article examines citizen science as situated urban politics in Siena, Italy, through two initiatives engaging students, residents, migrants, volunteers, and researchers in documenting everyday urban life and river ecosystems. Drawing on ethnographic engagement, data walks, and interviews, we argue that citizen science produces more than data: it becomes a relational practice through which participants negotiate belonging, enact presence, and challenge epistemic hierarchies in urban governance. The article shows how digital platforms both enable participation and act as epistemic gatekeepers, making friction a diagnostic and transformative force for more responsive urban knowledge practices.

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1. Introduction

In a city like Siena – small, historic, and tightly woven into centuries of civic tradition – participation takes a particular form. Between the narrow medieval streets and the rhythms of the Palio, local belonging is strong yet selective. Over recent years, two initiatives, Citizen Science (CS) for Siena (CS4Siena) and Citizen Science for Rivers (CS4Rivers), have sought to open this civic fabric to new participants such as international students, long-term residents, scientists, volunteers, and migrants. Through data walks, workshops, and environmental monitoring, these projects invited citizens and non-citizens alike to re-imagine what it means to take part in Siena's urban and ecological life. These experiments also brought into view recurring frictions: moments where lived experience, participatory aspiration, and institutional logics did not align (Tironi 2020; Tsing 2005). As participants tried to make their observations count, whether on housing precarity, social integration, or river wellbeing, they encountered the limits of institutional recognition and the difficulty of translating situated experience into standardized data practices. In Siena, participation thus emerged not only as a civic promise but also as a site of contestation.

These tensions resonate with broader debates on how CS reconfigures relations between citizens, experts, and institutions (Danke, Hecht, and Hutter 2024; van Dijk, 2024). Rather than treating participation as self-evidently inclusive, recent

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work shows that such practices are shaped by selective framings, contingent data practices, and uneven institutional uptake. This article asks how citizen-generated data practices reconfigure belonging, expertise, and authority in the city, and how institutions move from registering contributions to actively listening and responding to them.

At first glance, Siena, characterized by a deeply rooted civic culture and sense of community (Boos 2020, 2024), might seem an unlikely site for exploring experimental participation. Nonetheless, Siena occupies a distinctive position within Italy's landscape of CS. It is the birthplace of the Italian Citizen Science Association and home to some of the country's longest-running participatory initiatives, spanning biodiversity monitoring, environmental stewardship, and community mapping. This dense ecosystem of projects, combined with the city's deeply rooted traditions and relatively closed social fabric, renders Siena an illuminating context for examining how participatory knowledge practices intersect with questions of inclusion, institutional frictions, and sense of belonging.

Within this setting, CS4Siena and CS4Rivers play complementary roles. CS4Siena engaged international students in documenting and reflecting on everyday experiences of housing, mobility, and social life. CS4Rivers, coordinated by scientists in collaboration with CS organizations and local associations, extended these practices to the river ecosystems closest to the city, mobilising residents, students, and researchers in community-led environmental monitoring. Together, they demonstrate how CS becomes a domain where data, affect, and politics are entangled, shaping knowledge production and the recognition of who counts as a knower. The experience of CS4Siena and CS4Rivers suggests that CS in Siena is not simply about collecting or visualising data but about how civic participation is enacted, negotiated, and sometimes resisted within a historically dense and socially bounded urban milieu. From the vantage of a city long celebrated for its traditions yet increasingly entangled in global circulations of people, technologies, and ideas, these initiatives offer a lens onto the evolving politics of belonging in contemporary Europe.

The contribution of this article is twofold. First, it shifts debates on citizen science in urban research from participation alone toward *belonging*, understood as an affective, spatial, and political relation through which attachments to place, community, and governance are negotiated (Osborne, Drozdowski, and Qu 2025; Yuval-Davis 2011). Second, it treats friction not as failure or breakdown but as an analytical window onto the uneven translation of citizen-generated knowledge into institutional forms, digital infrastructures, and urban governance practices (Tironi and Valderrama 2018; Tsing 2005). In doing so, the article shows that the political force of citizen science depends not simply on participation, but on whether citizen contributions are institutionally taken up and responded to.

The article proceeds as follows. The next section outlines the research design and methods. We then situate Siena's participatory landscape and theoretical framing, before presenting the two empirical cases. The final sections analyse the frictions and forms of belonging emerging from these initiatives and reflect on their implications for urban governance and citizen science.

2. Research design and method

This article draws on a qualitative, interpretive research design grounded in sustained engagement with two citizen science initiatives in Siena between 2022 and 2025. We approach Siena as an embedded case in which participatory knowledge practices intersect with university infrastructures, civic associations, and municipal governance. Within this case, CS4Siena and CS4Rivers function as analytically distinct yet interconnected units. Framing the study in this way allows us to examine how similar aspirations of participation, civic learning, and urban engagement take shape under different institutional conditions: one initiative primarily anchored on teaching university Master's and Erasmus programmes, the other rooted in environmental monitoring and collaborations with citizens, local associations, companies, and public sector actors. Treating them as embedded units enables analytical differentiation within a shared urban ecology.

Between 2022 and 2025, we participated in both initiatives as observers, facilitators and co-researchers (Kusek and Smiley 2014). As scholars trained in the social sciences and economic geography, we engaged with the city while collaborating with scientific communities within the university and with key members of the CS association. Our involvement included co-designing participatory formats, organising workshops, advising on participation strategies, and integrating CS practices into teaching and public events. In practice, this positioned us simultaneously as colleagues, friends, facilitators, observers, and at times critics of the processes unfolding. Therefore, many of the insights mobilized in this article arise from formal and informal encounters, such as lunch conversations, preparatory meetings, corridor exchanges, and ongoing discussions that accompanied the development of the initiatives. This proximity offered a privileged vantage point on how participation was enacted, negotiated, and occasionally strained. At the same time, our embeddedness also shaped what became visible to us and how we interpreted it. Our presence sometimes contributed to the very participatory settings we later analysed, while our sustained involvement risked normalising assumptions internal to the projects and foregrounding the perspectives of those most engaged in them. We therefore treat our positionality not simply as a source of access, but as part of the empirical condition of the research itself. This means that the analysis is strongest in tracing how frictions, attachments, and negotiations emerged within the initiatives, but less suited to making representative claims about all participants or all possible experiences of citizen science in Siena (Kindon, Pain, and Kesby 2007; Mullings 1999; Nagar 2002; Rose 1997).

Participation pathways differed significantly across the two initiatives and are analytically consequential. CS4Rivers brought together heterogeneous social groups through largely voluntary engagement: environmental associations, local committees and unions, migrant support groups, retired residents, and, in some instances, employees sent by companies as part of corporate social responsibility programs. Engagement was episodic yet recurring, and motivations ranged from environmental concern and local attachment to institutional visibility. By contrast, CS4Siena was embedded within university teaching programs. Students participated as part of their coursework, motivated by pedagogical interest in urban space, planning practices, and field-based data collection. Their participation was thus both voluntary and educational, structured by

curricular requirements while remaining open-ended in its experiential dimension. These differing recruitment logics shaped who participated and how the sense of belonging was experienced and articulated: in CS4Rivers through civic commitment and local identification, in CS4Siena through learning trajectories, academic experimentation, and temporary attachments to place.

To deepen and interrogate our ethnographic observations, we conducted eight semi-structured interviews during the preparation of this article. The selection was deliberate rather than representative. Interviewees included key coordinators and heads of the initiatives who had been involved from their inception and possessed a longitudinal understanding of their development; actors operating at the interface with municipal institutions; and two students who occupied hybrid roles as both participants and research assistants. The number of interviews reflects our intention to engage in extended, in-depth dialogue with knowledge-rich actors central to the initiatives' organization and trajectory. The interviews were not designed to produce a representative cross-section of participants, nor to stand alone as an autonomous data corpus. Their analytical value lies instead in deepening ethnographic interpretation, clarifying institutional rationales, and testing competing readings of key episodes. This design, however, also introduces limits: because the interview material privileges organizationally central and highly involved actors, it is better suited to analysing project trajectories, mediation practices, and institutional tensions than to capturing the full range of participant experiences, including more peripheral, fleeting, or disengaged forms of involvement.

Our analysis builds on extensive participant observation conducted during data walks, river-monitoring sessions, stakeholder meetings, and university-based courses. Fieldnotes were written immediately following events and complemented by reflexive memos documenting informal conversations, affective atmospheres (Bates, Lin, and Goodale 2016), infrastructural misalignments (Tsing, Mathews, and Bubandt 2019), and micro-negotiations through which participation was stabilized or destabilized (Akrich 1992). The analysis paid particular attention to who felt able to join, who remained peripheral, and whose contributions became legible within the projects.

Analysis proceeded abductively (Tavory and Timmermans 2022; van Hulst and Lianne Visser 2024), moving iteratively between field materials and theory. Initial coding focused on recurrent situations of tension, attachment, institutional uptake, and learning. These codes were then refined through comparison across fieldnotes and interviews, and through dialogue between the authors regarding divergent interpretations of key events. Friction and belonging emerged as analytical lenses through repeated encounters with moments where experiential knowledge, institutional standards, and digital infrastructures failed to align.

3. Rethinking participation: from data practice to belonging

Across contemporary urban contexts, participation has become both a necessity and a problem (Kelty 2019). In an era defined by converging ecological crises, deepening socio-spatial inequalities, and eroding trust in institutions; the question of who holds the authority to produce knowledge about cities has become critical (Heur and 2020). Traditional technocratic governance, long reliant on centralized expertise

and top-down monitoring, increasingly proves inadequate to the plural and uncertain conditions of urban life (Harris 2023). As public faith in planning and environmental institutions declines, participatory frameworks have come to the fore as possible sites of democratic renewal (Sepehr and Felt 2023). As Blok and Farias (2016) point us to paying attention to the ‘technical democracy’ of urban politics. We are reminded that democratic practices increasingly unfold within and through infrastructures, technologies, and expert systems, where decisions about urban life are negotiated in both formal institutions and the material and technical arrangements, shaping how cities are governed and experienced. Here, participatory governance comes with the promise to redistribute epistemic authority, foreground civic agency, and foster collective forms of stewardship. Yet as these frameworks proliferate, so too do doubts about what participation actually achieves, and for whom (Felt and Fochler 2010).

Participation has never been an unambiguous good (Kelty 2017, 2019). Science and technology scholarship has long revealed its ambivalence: while often celebrated as democratic innovation, it can also serve as a technology of governance that legitimizes pre-defined agendas (Chilvers and Kearnes 2015; Marres 2015). The ‘tyranny of participation,’ as Cooke and Kothari (2001) famously termed it, persists in new guises. Contemporary studies show how participatory programs frequently operate within tightly managed institutional frames that delimit what can be said and by whom. Participation becomes a means of inclusion and a mode of control – an instrument for enrolling publics into pre-established logics of governance (Felt and Sepehr 2024). As Chilvers and Kearnes (2020) argue, participation is best understood as a *process of negotiation* rather than an outcome thereof: a terrain of shifting meanings, asymmetrical relations, and open-ended stakes. Its promise lies not in consensus but in how it exposes the relational and epistemic conditions of collective life.

In the digital age, these negotiations have both multiplied and intensified (Marres 2013). Digital infrastructures such as data portals, mapping platforms, and smart city dashboards, have expanded the arenas of civic engagement, transforming how publics perceive and interact with urban systems (Certomà 2021; Cardullo and Kitchin 2025; Vanolo 2019). Canelas and Hoehnk (2025) shown similar dynamics in digital place-making, where curated digital tools both reshape people’s encounters of urban environments and accelerate forms of attachment while simultaneously narrowing narratives of place. These insights parallel the tensions within digital CS, where mediation can both open and delimit possibilities for participation. Yet they also reproduce existing inequalities of access and literacy, privileging technologically fluent actors while excluding other ways of knowing (Sepehr 2025). Digital participation thus embodies a paradox: it renders civic life measurable and networked, even as it obscures the embodied, affective, and situated forms of knowledge that sustain it. Digital mediation does not resolve the politics of inclusion; instead, it makes these politics more visible, revealing how infrastructures materialize relations of trust, dependency, and control between citizens and institutions. Within this shifting landscape, CS has emerged as a particularly fertile arena for rethinking participation. Initially defined as the involvement of non-professionals in data collection, CS has evolved into a distributed set of practices mobilising citizens, scientists, and policymakers around shared environmental and social concerns (Gabrys 2014).

Early framings emphasized its instrumental value: the crowd-sourced generation of reliable data at unprecedented scales (Haklay 2013, 2018). More recent scholarship, however, situates CS as a social and political experiment in knowledge co-production (Planillo et al. 2021). As Danke, Hecht, and Hutter (2024) argue in their analysis of ‘Colouring Dresden,’ CS is inseparable from the institutional and political arrangements within which data are produced. Their work demonstrates how CS initiatives are shaped by selective framings, governance structures, and the political contingencies of urban contexts; reinforcing that participation is always situated and negotiated. In this view, CS functions as a *relation-making practice* that ties together humans, technologies, and environments while also gathering facts. Data operates as a mediator of connection; a material through which publics learn to attend to, care for, and make sense of their surroundings.

Understanding data as relational unsettles the assumption that participation is primarily cognitive or informational. Scholars in science and technology studies and environmental humanities have argued that knowing is inseparable from caring and sensing; that data collection itself is an affective and ethical act (Davies 2024; Mahony 2023; Vadiati, Chiappini, and Bangratz 2025). CS, from this perspective, becomes a *practice of care* and facilitates an ongoing negotiation of attention, curiosity, and responsibility that binds participants to places and to each other. What begins as measurement often becomes an experiment in what Haraway (2016) terms as *living-with* environments, in developing the capacities to notice and respond to change. As Ash (2019) suggests, such practices give rise to ‘sensing publics’ – i.e. collectives formed through shared attunement to ecological and social transformations. Participation, therefore, allows one to contribute with data to the system and allows to cultivate awareness, sensitivity, learning to record, interpret and value phenomena together (Gabrys, Pritchard, and Barratt 2016).

This reorientation reveals participation as a practice of belonging. Belonging, as Osborne, Drozdewski, and Qu (2025) and Hudani (2025) have shown, is both a feeling and a political condition: to belong is to feel at home and to be recognized as part of a collective. These readings position belonging not as a fixed state but as a fluid, contested, and continually negotiated process. The core conceptual contribution is to extend existing debates by focusing on the embodied, affective, and physiological dimensions of belonging through the lens of everyday walking, which Osborne, Drozdewski, and Qu (2025) term a ‘biosocial palimpsest.’ In the city, belonging more vividly unfolds through movement, interaction, and the negotiation of difference (Yuval-Davis 2011). In what follows, we extend these debates by examining how such negotiations materialize in Siena’s citizen science initiatives, where participation operates both as a mode of data production and as a site in which belonging, recognition, and the right to shape urban life are contested.

4. Learning through friction: negotiating knowledge and belonging in citizen science

Our involvement with CS4Siena and CS4Rivers confronted us directly with the dynamics of belonging outlined above. Participation was never only a technical task. To walk a transect line along the Tressa or the Bozzone, to stop in Via Camollia and

record noise levels or street temperatures, or to debate whether a murky patch of water counted as ‘pollution’ was also to perform a claim to Siena, to make one’s presence matter within its sensory, historical, and epistemic fabric (see more: Sanna et al. 2025). For many international students and residents, we walked with, the act of noting a pothole, a smell, or a bird call produced a fleeting but meaningful sense of *having a place* in the city. As one student explained during a data walk: *It’s the first time I feel like I can say something about Siena, not just live in it*. Participation thus exceeded the utilitarian purpose of generating datasets; it became a mode of civic inhabitation, an embodied enactment of belonging.

Much like in other cities where data walks, or community mapping assembles publics through co-presence, Siena’s projects created ephemeral collectives (Vohland et al. 2021). People lingered on bridges, paused in alleyways, compared notes on algae or litter accumulation, and narrated their routes through the city (Capineri, Salerno, and Stefania Sanna 2025). The river sessions frequently ended with informal conversations, e.g. stories of childhood summers along the Arbia or frustrations about student housing, that had little to do with data quality but everything to do with how publics come into being. These encounters resonate with Marres (2016) notion of *material participation*, where political life emerges through the infrastructures and devices that gather bodies, sensations, and concerns. The notebooks, thermometers, and mobile apps used in Siena were not passive implements; they mediated perception, attention, and connection, shaping how participants learned to inhabit the city differently (Capineri, Salerno, and Stefania Sanna 2025).

Yet, as both our fieldwork and the literature on digital mediation show, the infrastructures that enable participation also delimit it. Digital platforms, sensing tools, and data portals choreograph relations between participants and institutions, governing what becomes visible and what remains unsaid. These dynamic echoes recent debates coined by Canelas and Hoehnk (2025) which demonstrate how digital placemaking tools curate particular experiences of place, accelerating attachment while foregrounding selective narratives. In a similar way, the digital infrastructures used in Siena structured how participants could register their concerns. When students in CS4Siena attempted to report despair, exclusion, or feelings of social isolation during mobility mapping, these experiential concerns often resisted the categories provided by the facilitators. Likewise, during river monitoring, residents’ observations that ‘the river feels quieter this week’ or ‘smells stronger than usual’ were difficult to translate into quantifiable indicators. Infrastructures, as Ash (2019) suggests, are spatial imaginaries that prescribe what counts as valid knowledge. They also produce what Larkin (2013) calls *infrastructural affect*: moments of anticipation, frustration, or satisfaction that shape the emotional terrain of engagement.

These affective infrastructures structured both the promise and precarity of participation. On the one hand, platforms produced immediate visibility, for example, pins dropped on maps, color-coded outputs, dashboards displaying the ‘impact’ of one’s contributions. For students unused to being acknowledged within Siena’s tight civic fabric, these visualizations offered a form of recognition. On the other hand, contributions often travelled into institutional systems without response. Participants in both initiatives expressed discouragement when no follow-up occurred: *‘We sent all this information ... and then what?’* one student asked after

a housing data walk. This asymmetry reflects what Cardullo and Kitchin (2025) describe as digital enclosure; the one-way capture of civic contributions into institutional infrastructures with limited return. Participation thus oscillated between empowerment and exhaustion, depending on whether infrastructures reciprocated attention.

Friction makes these oscillations visible. It indicates the slow, situated rubbing of heterogeneous practices that renders asymmetries perceptible and open to negotiation. In Siena, friction emerged in subtle but consequential ways. During CS4Rivers sessions, debates erupted around ‘proper’ sampling methods: scientists insisted on consistent transects, while long-term residents argued that seasonal rhythms or historical memory of flooding mattered more than standardized intervals. These disagreements did not hinder the project; they enriched it, revealing multiple ways of knowing the river. Similar frictions surfaced in CS4Siena, where students challenged the assumption that housing problems could be captured through quantitative metrics alone. In both cases, friction became a moment of reflexivity, prompting researchers to reconsider their assumptions and enabling participants to articulate alternative, situated forms of knowledge. From this perspective, CS is always embedded in political and institutional arrangements, shaped by selective framings and strategic omissions.

Attending to friction reveals participation as a form of civic learning. Through repeated encounters with tools, experts, infrastructures, and each other, participants acquired new capacities to sense, interpret, and act. Gabrys, Pritchard, and Barratt (2016) describes this as *citizen sensing*, a pedagogy through which publics learn to perceive environmental change and articulate its significance. In Siena, this learning was affective as much as cognitive. Participants experienced curiosity when spotting new species, pride when identifying pollution sources, and frustration when contributions vanished into institutional workflows.

Over time, many participants developed a certain awareness of urban inequality and ecological vulnerability, recognising the asymmetries of attention that shape which issues are considered legitimate. But this learning remained fragile. When feedback loops failed, when municipal responses were slow or absent, or when technical constraints made certain concerns illegible, the attachments sustaining participation risked unravelling. Belonging in CS is therefore a provisional achievement. It relies on continuous labor, responsiveness, and negotiation. Knowing and belonging remain partial and contingent, requiring maintenance and reflexive awareness. From this perspective, friction becomes a pedagogical site. It reveals the limits of existing arrangements and creates opportunities for more pluralistic and responsive forms of governance.

Overall, rethinking participation through the lens of Siena’s citizen science initiatives reveals how data practices, care, and belonging are intertwined in the production of urban knowledge. Participation becomes a relational practice that binds people to places and to one another through shared acts of sensing and interpretation. Digital infrastructures mediate these relations, offering both openings for inclusion and sites of friction. Through the tensions they generate, participants engage in forms of civic learning rooted in recognition, responsibility, and the aspiration for institutional responsiveness. It is within these fragile and contested negotiations that CS4Siena and CS4Rivers must be understood.

5. Citizen science and the politics of urban belonging in Siena

5.1. CS4Siena: negotiating belonging in a closed city

At the centre of CS4Siena was a deceptively simple task: to document international students' experiences of urban life in Siena focusing on housing, mobility, sustainability, and social integration. Yet the project quickly outgrew its initial remit. What had been framed as a quantitative data collection exercise began to reveal something more fundamental: that for many students, the issue was not simply poor housing or uneven mobility but the struggle to *feel part* of the city at all. The methodological openness of the facilitators allowed this shift to occur, but it was participants who insisted that their lived experiences could not be compressed into numerical indicators. Early workshops made evident that students sought not only to measure urban quality of life but also to articulate the emotional and social labour of inhabiting Siena.

Siena itself amplifies these dynamics. Internationally celebrated for its medieval beauty, the Palio, festivals, and traditions, the city welcomes outsiders as visitors while often resisting their integration as residents. Interviewees repeatedly described Siena as both enchanting and impenetrable. Many students, including Italians from outside Tuscany, referred to the city as 'closed', 'tight', or 'hard to enter socially'. These descriptions were not simply complaints about social life but reflections on how urban belonging is structured by historical identity, local attachments, and civic pride. In this context, CS4Siena acted as a small but significant breach in Siena's social boundaries: a sanctioned space where students could narrate experiences that often remained muted in everyday encounters.

Belonging, as it emerged in CS4Siena, was not tied to legal status or the duration of residence but to *recognition*. Through interviews, students described the project as the first time they were asked what mattered to them in the city. Concerns ranged from mold-infested rooms and exploitative rental contracts to the sensation of feeling watched in certain neighborhoods or being excluded from local gatherings. These narratives enacted what Hudani (2025) distinguishes as the dual dimension of belonging: the intimate sense of 'being at home' and the political condition of being acknowledged as part of a collective. CS4Siena made room for both, enabling participants to articulate their discomforts while beginning to claim authority over Siena's civic discourse. A critical factor in this process was the facilitators' stance. Instead of prescribing issues to be mapped or surveyed, students were invited to identify what they sensed and where they experienced tensions in their daily routes. This approach reflected broader debates in CS about the shift from extractive data collection to co-produced, situated knowledge practices (Planillo et al. 2021). It also aligned with the critique emerging in Danke et al.'s (2024) study, which argues CS becomes meaningful when space is created for participants to actively shape the project's epistemic contours rather than being ascribed to predefined categories (Bieszczad, Fochler, and Brodschneider 2023). In Siena, this openness fostered what might be called *epistemic communities of care*: loose collectives formed through shared attentiveness during walks, workshops, and informal conversations.

The data walks were particularly generative. As we moved through *Via Camollia*, the *Fortezza* gardens, or the steep paths leading to *Antiporto*, students observed not only infrastructural breakdowns (e.g. broken pavements, narrow crossings, dimly lit

underpasses) but also broader patterns (e.g. subtle social cues, uncanny networking possibilities via following QR tags in the streets, awkward interactions with tourists, microaggressions, or spaces where they felt unusually at ease). These embodied practices blurred the line between sensing and reflecting. One student noted privately that the walk ‘made me see where I belong and where I don’t’ an observation that echoed others who said they had ‘never walked Siena this way.’ While all the walks catalyzed a transition from passive occupation of the city to active civic inhabitation, echoing Canelas and Hoehnke’s (2025) argument that digital and material practices can accelerate forms of attachment, the Siena case exhibited a noticeably slower pace, mediated through frictions and often heavily negotiated. Yet, these relational achievements were consistently shaped by frictions, both infrastructural and epistemic. Digital surveys, despite their accessibility, were frequently criticized for reducing rich experiences to surface-level metrics. Workshops, though more dialogical, revealed uneven dynamics: confident English or Italian speakers tended to dominate, while quieter participants withdrew. These tensions resonate with critiques in participatory studies that highlight how tools meant to democratize engagement often reproduce existing inequalities, unless continually reworked (Felt and Sepehr 2024).

The most consequential friction, however, emerged at the interface between student-generated knowledge and institutional expectations. Many participants were frustrated when their contributions were labelled anecdotal or insufficiently rigorous. This tension was palpable in one exchange where a student objected to calls for ‘neat’ data by responding: ‘The city is messy, why can’t our data be?’ What was at stake here was not methodological neatness but epistemic legitimacy. Institutional preferences for standardized indicators rendered certain experiences (e.g. feelings of isolation, insecurity, or exclusion) difficult to translate. Drawing on Leonelli and Tempini’s (2020) notion of the *data journey*, we can see how participants disrupted the normative filtering mechanisms that typically privilege sanitised datasets over messy lived accounts.

Notably, the most profound sense of belonging often formed outside formal sessions. After workshops, students lingered in the courtyard or local bars, continuing conversations that had been constrained by the structure of the meeting. Informal gatherings such as sharing *aperitivi*, exchanging housing tips, comparing encounters with local bureaucracy, became integral to the project’s affective life. They made visible the relational infrastructures of care that CS can generate when institutional framing does not crowd out sociality. Participants repeatedly described these moments as ‘relief’, ‘comfort’, or ‘knowing I’m not alone’, highlighting how belonging is cultivated through shared vulnerability as much as through data-making. Thus, CS4Siena demonstrates that citizen science can act as a political and pedagogical practice of belonging in contexts where social boundaries are tightly drawn. The initiative neither radically transformed institutional structures nor definitively produce a dataset on student life. Instead, its significance lies in the small shifts it enabled: students learning to see themselves as legitimate commentators on the city; facilitators rethinking what counts as evidence; and the project revealing, through friction, the epistemic hierarchies that shape urban governance. Through these situated practices, CS4Siena reframed participation as a practice through which participants *claim presence* and negotiate authority, recognition, and attachment in a city that is both inviting and exclusionary.

5.2. *Situated knowledge and institutional frictions: the case of CS4Rivers*

While CS4Siena illuminated how CS can cultivate relational attachment and affective belonging, CS4Rivers made visible a different set of challenges: how situated ecological knowledge encounters, contests, and occasionally transforms institutional expectations. Designed to democratize ecological monitoring, CS4Rivers brought together elderly residents, migrants, scientists, and environmental volunteers to collectively observe riverine change. Yet beneath its collaborative ethos, the project exposed fundamental questions about epistemic legitimacy: which forms of ecological knowledge count, and who gets to define the terms of environmental governance?

From the outset, participants treated the river as far more than a hydrological system. In interviews and spontaneous conversations along the riverbanks, residents narrated memories of fishing with parents, of childhood summers, of floods that had reshaped neighborhoods. Migrant participants drew translocal parallels comparing, for example, the Tressa to the Nile or to rivers in their home regions, highlighting how ecological belonging is carried across places. These reflections repositioned the river as a socio-cultural space where memory, identity, and care accumulate. They also challenged technocratic framings that treat rivers primarily as objects of management and foregrounded understandings of rivers as dynamic multispecies landscapes. Understanding the river required attention to chemical indicators and geospatial mapping, as well as to the lived and affective registers through which participants sensed, valued, and interpreted ecological change.

It was precisely this richness that clashed with institutional logic. Across field encounters, frustration emerged around how participants' observations were translated into reporting frameworks. Detailed accounts of sedimentation, invasive species, or seasonal changes often reappeared in official outputs as simplified markers such as color-coded risk categories or isolated dots on a dashboard. This flattening mirrors the dynamics described by Tironi (2020), where data-driven citizen science platforms rendered complex local knowledge legible to institutions only by stripping away context. In Siena, the same reductive tendencies were palpable. Participants expressed disbelief when their repeated documentation of problematic stretches resulted in a single undifferentiated 'red dot'. Scientists involved in the project acknowledged the tension because institutional systems demanded standardized indicators, while citizens offered stories, sensory impressions, and attachments that resisted neat categorization. These frictions were not mere misunderstandings; they revealed deeper epistemic hierarchies.

Citizen-generated knowledge was often implicitly positioned as anecdotal, messy, or insufficiently rigorous. Such classifications exposed the governance infrastructures through which environmental issues are rendered actionable. As one local scientist put it, the municipality 'expects numbers, not narratives'. Yet, the insistence of participants that their relational observations mattered functioned as a quiet but consequential challenge to these hierarchies. By foregrounding the river ecosystems as lived and storied, participants expanded the scope of what ecological monitoring could be, and what it should account for. Also in this case, project facilitators sought to work with them and embrace these challenges as generative. Alongside digital tools and surveys, they introduced guided walks,

collective reflection sessions, and storytelling moments that foregrounded the affective and historical dimensions of the river. These embodied practices rebalanced the epistemic terrain. A PhD researcher coordinating the project described realising that ‘apps and surveys alone were not enough’ because participants needed to walk together, to share memories, to situate observations within broader ecological rhythms. Echoing broader debates in environmental humanities and STS, these interventions affirmed that ecological knowing is neither purely cognitive nor purely technical but emerges through attunement, co-presence, and shared world-making.

Nevertheless, methodological innovation did not resolve all barriers. Structural inequalities continued to shape participation. Migrants, elderly residents, and economically precarious groups remained underrepresented, not out of disinterest but because participation demanded time, language skills, and familiarity with institutional or digital practices. Facilitators repeatedly noted that meaningful engagement required long-term trust-building; often beyond the temporal and financial constraints of the project. CS4Rivers, consequently, made visible how inclusion depends on institutional capacity to engage with diverse temporalities, capacities, and forms of life. Institutional inertia, in fact, emerged as the most persistent obstacle. While municipal officials publicly praised the initiative, participants doubted its influence on decision-making. Mapping outputs were acknowledged but not integrated into planning routines; reports were received politely but rarely acted upon. This gap between symbolic recognition and substantive uptake exemplifies what scholars of participatory governance identify as performative inclusion: participation that checks boxes without redistributing authority. One participant described this dynamic as ‘the city listening without hearing’, a formulation that captures the epistemic distance between citizen-generated insight and bureaucratic responsiveness.

Despite these constraints, CS4Rivers cultivated a relational infrastructure of care that exceeded the project’s formal objectives. Participants emphasized that their involvement fostered community and that they learned to recognize ecological signals together, compared observations across seasons, and developed shared commitments to local rivers. Through these collective practices, the river was reconfigured from a taken-for-granted, background landscape into a civic arena where environmental stewardship, social learning, and political engagement intertwined. Here, friction becomes a generative force rather than an obstruction, exposing institutional blind spots, prompted methodological rethinking, and enabled participants to build solidarities around ecological change.

In this respect, CS4Rivers shows that citizen science in Siena functions less as a pipeline for policy-ready data and more as an experiment in pluralistic environmental governance. Situated knowledge (including memories, sensations, rhythms, and stories that participants brought to the river) was central to how ecological issues were understood and acted upon. Institutional frictions revealed the limits of existing governance frameworks and pointed to openings for more responsive, relational, and democratic practices. In this light, CS4Rivers provided a venue for the real-time renegotiation of the politics of ecological knowledge, care, and authority.

5.3. Digital frictions of participation across CS4Siena and CS4Rivers

Across CS4Siena and CS4Rivers, participation unfolded as a set of relational and infrastructurally mediated practices through which claims to belonging and authority were negotiated. In both initiatives, data mediated participants' presence in the city. Students mapped precarious housing while simultaneously navigating their peripheral position in Siena's social fabric. River volunteers recorded ecological change through memories and attachments that exceeded hydrological measurement. Sensing, in this context, was inseparable from negotiating recognition.

Yet as Leonelli, Rappert, and Davies (2017) argue, data acquire value only through the infrastructures that classify, stabilize, and circulate them. It was precisely in these infrastructural passages that friction became most visible. The formats embedded in digital tools such as survey boxes, mapping icons, and dashboards privileged discrete and standardized inputs. Numeric data traveled smoothly; narrative and affective accounts did not. Richly storied ecological observations reappeared as undifferentiated 'red dots'; layered accounts of exclusion were reduced to Likert-scale ratings. These transformations were not neutral technical translations but epistemic operations that aligned citizen contributions with bureaucratic logics while attenuating their situated complexity.

In this sense, digital infrastructures functioned as epistemic gatekeepers. They enabled participation by inviting contributions while delimiting what could circulate as legitimate knowledge. Participants themselves recognized and named these constraints. Students questioned why their experiences needed to be 'neat'; volunteers noted when repeated observations disappeared into institutional systems without response. Friction here acted as an epistemic revealer, exposing the classificatory commitments and accountability regimes that structure urban governance.

Importantly, friction also prompted processes of recomposition. Facilitators in both initiatives blended digital methods with embodied and dialogical practices, including storytelling sessions, collective walks, informal gatherings. These hybrid arrangements aimed to preserve context, resonating with Leonelli's (2020) calls for data practices attentive to situatedness. Through such recompositions, participation shifted away from data extraction towards relational engagement, wherein co-presence enacts belonging. The juxtaposition of the two initiatives exposes distinct but related registers of digital friction. In CS4Siena, friction centered on the social intelligibility of lived experience within standardized participatory infrastructures. In CS4Rivers, it concerned the ecological intelligibility of dynamic environments within rigid environmental management systems. In both cases, however, friction exposed a shared condition: governance infrastructures were not designed to receive the forms of insight participants produced.

Citizen science in Siena thus emerges as *participation-in-politics* where digital infrastructures, urban subjectivities, and institutional logics intersect. Friction makes visible the institutional architectures that shape whose knowledge travels, whose attachments are recognized, and how urban learning occurs. Additionally, these initiatives are demonstrative of how frictions can facilitate pluralistic and responsive forms of urban governance.

6. Discussion: friction, data journeys, and participation-in-politics

Citizen science in Siena offers a lens into the politics of contemporary urban participation, where data collection, belonging, and governance are inseparable. Across CS4Siena and CS4Rivers, what began as small-scale experiments in participatory sensing became sites in which questions of recognition, epistemic authority, and democratic possibility were negotiated in practice. Read together, the initiatives illuminate four interrelated dynamics: friction as a structural feature of data journeys; digital infrastructures as epistemic gatekeepers, friction as diagnostic and generative; and participation as a political practice enacted through claims to presence.

6.1. Friction as a feature of data journeys

A first key insight concerns the nature of friction in the circulation of citizen-generated data. Drawing on Leonelli's (2020) notion of *data journeys*, our findings show that data do not move seamlessly from lived experience into policy arenas. They are translated, reformatted, classified, and stabilized through infrastructures that privilege certain forms of knowledge over others. International students' accounts of exclusion and residents' affective memories of the river were compelling as situated knowledge, yet struggled to become 'mobile data', information that institutions can aggregate and operationalize.

Their limited mobility arose from infrastructural assumptions about what counts as evidence. The reduction of richly contextualized accounts into abstract map markers or standardized indicators reflects a structural friction: institutional systems are calibrated to numeric, discrete, and comparable inputs. Frictions emerge precisely at this juncture, where experiential and relational forms of knowing encounter classificatory regimes that demand legibility and uniformity. This friction is not incidental; it is constitutive of the movement from lived experience to institutional evidence.

6.2. Digital infrastructures as epistemic gatekeepers

These frictions draw attention to digital platforms as *epistemic gatekeepers*. Platforms are not passive conduits for participation; they embed assumptions about valid knowledge. In CS4Rivers, reporting tools captured invasive species sightings but not the slower ecological transformations sensed by long-term residents. In CS4Siena, surveys registered housing satisfaction but struggled to accommodate anxiety, exclusion, or social precarity.

Such omissions exemplify what Leonelli (2020) terms data injustice: the structural exclusion of knowledge types that do not fit standardized templates. Digital infrastructures, thereby, play a part in the shaping of the circulation of data and whose insights are made visible and actionable. Participants encountered these filtering viscerally when reports disappeared into institutional 'black boxes' or when complex observations reappeared as simplified output. The result was an oscillation between empowerment – seeing one's contribution mapped, and estrangement – recognising that what mattered most had been flattened. Digital mediation thereby configured the conditions through which claims to belonging were articulated. Infrastructures also delimited the epistemic formats through which participation gained institutional recognition.

6.3. Friction as a diagnostic and generative

Friction exposes infrastructural limits and also generated reflexivity. Participants questioned why ‘messy’ data were excluded, why repeated observations received no response, and why certain experiences remained illegible within reporting systems. These moments prompted facilitators to experiment with hybrid arrangements that combined apps and surveys with collective walks, storytelling sessions, and dialogical workshops. Friction functioned simultaneously as diagnosis and generative process: it revealed where governance logics resisted adaptation, and it opened space for alternative modes of knowledge-making. Students and river volunteers expressed demands for epistemic justice, calling for the recognition of relational, affective, and situated insights as legitimate forms of urban and ecological expertise. In this sense, friction contributed to the reconfiguration of entrenched hierarchies through making institutional assumptions visible and open to negotiation.

6.4. Participation-in-politics

Synthesising insights across both projects indicates that CS in Siena can be conceptualised as *participation-in-politics*. Contributing data became a way of claiming presence by asserting the right to speak about the city and to be recognized as part of it. This dynamic was particularly evident among groups positioned at the margins of urban politics including international students, migrants, precarious residents. Their contributions carried informational value and also expressed claims to belonging. Belonging in this context emerged as a provisional achievement shaped through shared practices of sensing, walking, noticing, and discussing. Through these activities, participants positioned themselves as knowledgeable urban actors, and challenged the implicit monopoly of planners, scientists, and policymakers over urban expertise. Participation therefore exceeded contribution and became a struggle over recognition.

At the institutional level, however, these claims encountered a persistence gap between participatory rhetoric and epistemic accommodation. As mentioned before, one participant described this dynamic as ‘the city listens without hearing,’ a formulation that captured the frustration of seeing contributions acknowledged but not acted upon. Municipal actors often welcomed contributions procedurally, yet, struggled to integrate them substantively. This distinction becomes crucial. Institutions may register, store, and acknowledge citizen-generated data without allowing those contributions to reshape priorities, classifications, or decisions. In Siena, friction marked this gap between *procedural receptivity* and *institutional response*. It appeared when data were captured without follow-up, when narratives were acknowledged without being integrated into decision processes, and when participation occurred without organizational change.

7. Conclusion: from registering input to responding

The cases of CS4Siena and CS4Rivers demonstrate the inter-involvement of data practices, infrastructures, and institutional routines in shaping who is recognized as a knowledgeable urban actor. This complexity shows that citizen science in

urban contexts cannot be reduced to the technical expansion of participation. Rather, friction reveals the politics embedded in data journeys: meaningful participation depends less on the volume of collected data than on the capacity of institutions to adapt and respond to the knowledge produced through participatory processes. This analysis does not aim to represent all participant experiences across Siena's citizen science landscape; rather, it offers an interpretive account of how belonging, friction, and institutional responsiveness became visible through two closely followed initiatives. What is ultimately at stake, then, is the gap between registering citizen contributions and responding to them institutionally. Registering refers to forms of procedural receptivity: platforms that collect inputs, consultations that invite feedback, and dashboards that visualize contributions. Responding, by contrast, implies institutional willingness and capacity to let citizen-generated knowledge alter classifications, priorities, and governance routines. In Siena, participation often achieved the former without fully achieving the latter.

This insight extends beyond Siena. Across European and global cities, citizen science and digital placemaking initiatives are increasingly institutionalized as instruments of participatory governance. Yet the Siena experience suggests that their democratic potential hinges not only on access or engagement metrics but also on whether governance systems are designed to accommodate situated, relational, and affective forms of knowledge. Friction should therefore be understood as an analytical indicator of where institutional architectures remain misaligned with the forms of insight citizens produce.

For urban research, this implies several priorities. First, greater attention should be paid to the *afterlives* of data and how citizen-generated knowledge travels, stalls, or mutates within administrative infrastructures. Ethnographic engagement with data journeys can reveal the often invisible transformations that determine whether participation becomes politically consequential. Second, comparative research across cities and institutions is needed to examine how different governance regimes absorb or resist situated knowledge. Third, future work should interrogate how digital infrastructures themselves are designed, governed, and iteratively modified, moving beyond participation as input toward participation as institutional co-learning.

For practitioners and policymakers, the implications are equally clear. Designing participatory initiatives requires more than user-friendly platforms. They necessitate the fostering of hybrid infrastructures, which preserve contextual information, integrate narrative and embodied practices with quantitative metrics, while establishing feedback mechanisms show how contributions inform decisions. Friction can also serve as a diagnostic resource, helping to identify institutional blind spots and support the revision of epistemic assumptions.

Ultimately, CS in Siena demonstrates that knowing and governing the city are co-produced through everyday practices of noticing, negotiating, and caring. Participation becomes political through processes in which citizens articulate their experiences and institutions respond to the knowledge produced through these engagements. The democratic promise of citizen science lies in moving beyond the procedural collection of voices toward forms of institutional response that redistribute authority and reshape urban governance.

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Data availability statement

Due to the qualitative and confidential nature of the interview data, participants' anonymity is protected. Data are available from the corresponding author upon reasonable request.

Human participants

All interview participants provided informed consent. Ethical procedures were followed in accordance with the University of Siena research ethics guidelines.

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