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Co-designed citizen science insights for geoscientists: making sense of complex relations

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Abstract. Citizen science can expand data collection and connect research with society but involving non-scientific stakeholders introduces complex relations that challenge conventional geoscientific practice. This paper examines these dynamics through the lens of ISOSCAN, an interdisciplinary project that co-designed a citizen science programme for collecting stable water isotope samples across Scandinavia. Co-design workshops, prototype testing and the analysis of five *vignettes* (short narratives) authored by scientists were used to uncover these complex relations. Three themes emerged: epistemic tensions between scientific precision and diverse stakeholder objectives; mutual learning that reshapes disciplinary assumptions and practical protocols; and the centrality of trust and iterative processes over strict methodological control. We make sense of the complex relations and offer insights into how co-designed citizen science can promote interdisciplinarity and methodological innovation in geoscience.

1 Introduction

Against the backdrop of global environmental crises and sustainability challenges, geoscientists are increasingly urged to consider non-scientific and non-academic groups, including the wider public, as integral to the research process. This may involve adopting open science practices (de Vos et al., 2020), or more broadly reconsidering the role of science in other forms of knowledge creation, for example, by co-creating water knowledge with communities (Castelli et al., 2025). Another format is citizen science, broadly understood as participation in research by individuals who are not professionally trained in that particular field (Illingworth, 2023; National Academies of Sciences, Engineering, and Medicine, 2018). As with other approaches to engaging non-scientists in science, proponents of citizen science present it as a mutually beneficial

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arrangement. It strengthens the connection between science and society while enabling high-quality environmental and geoscience research – not least because a large number of citizens can be involved in collecting or analysing data (Appels et al., 2017; Assumpção et al., 2018; Crumley et al., 2021; Nardi et al., 2022; Njue et al., 2019; Ocampo-Melgar et al., 2022; Ramírez et al., 2023; San Llorente Capdevila et al., 2020; Unterfrauner et al., 2024).

Despite these calls and arguments, citizen science and other forms of public involvement are relatively rarely applied in the geosciences. For instance, Vanelli et al. (2022) found that, despite socio-hydrology's explicit focus on the interactions between society and water, only just over a third of studies published up to 2020 involved stakeholders outside academia, such as citizens, decision makers, and policymakers. Scientists may have various concerns about incorporating citizen science into their work, such as unfamiliarity with methods of working with non-scientists and concerns about data quality (Burgess et al., 2017; Riesch and Potter, 2014). Conventions, practices, and even values related to scientific research can also prevent scientists from collaborating with other professional researchers across disciplines (Newman, 2025). Differences in backgrounds and interests of non-scientists can be even greater, making communication and cooperation particularly challenging (Colquhoun et al., 2013). Importantly, the benefits of participation for non-scientists are not automatic. Participation can even have negative impacts, such as disempowerment and the creation of conflict, particularly in vulnerable communities (Walker et al., 2021). Given the variety of goals held by scientists and citizen scientists, designing citizen science can thus be conceived as a complex, if not outright "messy" undertaking (Hoadley, 2017). Without understanding the added value of the complex aspects of the scientific process that come with engaging with citizen science, a citizen science approach may seem unappealing or difficult to justify.

In this article, we apply complexity theory as a lens for understanding geoscientific and citizen-science practices in which outcomes emerge from nonlinear, interaction-driven relations (McDonald, 2009). Rather than viewing scientific processes as linear pipelines, complexity theory emphasises how evolving interactions between citizen scientists, professional scientists, technologies, and environments generate emergent patterns, shape data quality, remakes and influence interpretive practices (Groves, 2017; Meekes et al., 2023). Making sense of these complex relations, we identify the distinct forms of value that professional scientists perceive when involving non-scientists in co-designed citizen science. Highlighting the value of navigating the often complicated relationships with various scientific and non-scientific stakeholders could encourage more scientists to engage with citizen science (Golumbic et al., 2017). Equally, scientists who are already interested in, or actively engaged with, citizen science would benefit from a deeper awareness of how the nonlinear dynamics of research involving active citizen participation can productively inform and enrich their scientific work. Such knowledge may inform the refinement of one's own practice and support its effective communication to collaborating researchers or potential funding bodies.

We do this in the case of the ISOSCAN project, which stands for "Isotope-aided assessment and forecasting of hydroclimatic extremes in Scandinavia through stakeholder co-design" that started in April 2024. The project aims to improve prediction models of hydrometeorological extremes in Scandinavia, such as floods and droughts, by using stable water isotopes information from precipitation, snow, soil, as well as ground and surface water. Conventional scientific observations are

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complemented by citizen scientists – recreational nature users (both locals and tourists) in different parts of Scandinavia – who primarily collected surface snow samples, as well as water samples from small streams. Crucially, the citizen science programme itself, including the recruitment strategy, sampling protocol and communication processes, was co-designed by project scientists and non-scientific stakeholders. These stakeholders included prospective citizen scientists, as well as representatives of local organisations, tourism and leisure businesses, and an international school. The project was led by an international, interdisciplinary team of meteorologists, hydrologists as well as anthropologists and social scientists specialising in tourism research, co-design and citizen engagement. The project team is based in Norway, Sweden, Finland and Denmark.

Before outlining the iterative co-design process, the paper's research methodology and its results, we provide a brief overview of the literature on the participation of non-scientific stakeholders in citizen science, as well as the co-design approach that informed the iterative process in ISOSCAN. The scientific rationale and background for using stable water isotopes as tracers for forecasting hydroclimatic extremes are explained throughout the article only to the extent necessary to understand the value of the complex aspects of the scientific process. More in-depth discussions of these elements of the project are beyond the scope of this article.

2 Citizen science and co-design in the literature

2.1 Participation in citizen science

The term "citizen science" is not a strictly defined and is used in diverse and sometimes inconsistent ways across different disciplines and practices. At its core, citizen science involves the active participation of non-professional scientists, or citizen scientists, in scientific research, contributing to data collection, analysis, and even interpretation. The literature lists numerous advantages for implementing citizen science, such as the enabling of novel and innovative contributions to scientific knowledge by expanding data collection and data processing capacities, influencing policy, as well as more broadly democratizing science with the potential for changing behaviours (Fraisl et al., 2022; Shirk and Bonney, 2018; Unterfrauner et al., 2024). For example, involving citizen science in hydrology and other water-related sciences help fill data gaps, improve water management, but also change the perspectives of both professional scientists and citizens on water and its role in our lives (Buytaert et al., 2014; Castelli et al., 2025; Nardi et al., 2022).

The design of any citizen-science project is shaped by the specific interests, perspectives, and priorities of the people involved in its development. For example, a citizen science project initiated by professional scientists may emphasize the procedures for data quality, while a grassroots-initiated project may prioritize policy influence. Nevertheless, outcomes may be unexpected. For example, Ocampo-Melgar et al. (2022) described how stakeholder participation in hydrological modelling in the Aculeo basin in Chile helped the model address issues that had caused suspicion and conflict among stakeholders. Furthermore, the specific outcomes of participating in citizen science are likely to differ not only between professional citizens and citizen scientists, but also within these groups. Similarly, some professional scientists may be

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concerned about the distribution and quality of data, while others may be primarily driven by increasing the social legitimacy of their research, i.e. the broad public trust afforded by society (Collins et al., 2023; Vann-Sander et al., 2016; Webster and Dennison, 2022).

Depending on the type of participation by non-scientists, theorists of citizen science distinguish between various forms, models, or types of citizen science. In contributory citizen science projects, non-scientists contribute data to scientist-designed projects. In collaborative projects citizens are involved in refining methods, analysing data or disseminating findings, while in co-created projects citizens and scientists jointly define research questions and methods (Bonney et al., 2009). Shirk et al. (2012) add two more categories – contractual and collegial projects, while Haklay (2013) has proposed a ladder of participation in citizen science, starting from "crowdsourcing" data by citizens, moving on to "distributed intelligence" (e.g., citizens analysing data), "participatory science" (citizens participating in problem definition and data collection), and finally "extreme citizen science" (scientists as facilitators rather than drivers of the scientific process). Contributory citizen science, roughly corresponding to crowdsourcing and distributed intelligence, appears to be the most common approach in the published literature, including in the geosciences. This is arguably because academic literature tends to publish studies led by scientists rather than grassroots projects where more extreme or community-driven forms of citizen science are likely to emerge. In addition, many analytical methods used in environmental and geosciences are technically demanding and less accessible to the general public than those commonly employed in the humanities and social sciences, where collaborative and co-created forms of citizen science are more prevalent.

The increased availability of inexpensive and reliable sensing equipment, including smartphones, has enabled the distribution of sensing capabilities across large numbers of people, far beyond the reach of professional scientists (Buytaert et al., 2014; Fraisl et al., 2022; Njue et al., 2019). Yet despite the emergence of the term "citizen sensors," citizens cannot be reduced to an instrumental role, as their sensing practices are inseparable from their personal lives, interests, and motivations. Nor can such activities be considered synonymous with those of professional scientists, since they take place under very different circumstances. For example, they may be a brief part of leisure activities with family or friends, rather than a routine part of one's work. Also, the contexts for involving citizen scientists vary considerably. Professional scientists cannot anticipate the specific motivations or interests that citizens bring to a project, particularly because citizens themselves may not fully recognise these motivations prior to participating.

In geosciences, citizen science participation entails engagement with distributed and dynamic phenomena, such as hydrological regimes, seismic activity, soil conditions or coastal change, where situated and heterogeneous observations can reveal variability and thresholds that centralized monitoring may overlook (Buytaert et al., 2014; Silvertown, 2009). At the same time, participation in citizen science, as an inherently collaborative practice, is also complex, situated, and contingent because it arises from the interdependencies and evolving social processes that develop among participants (Mosleh and Larsen, 2021). From a complexity theory perspective, such interactions generate patterns, constraints, and possibilities that cannot be predicted from the individual components alone, such as the interests, intentions, and actions of citizens or scientists involved in the process (Meekes et al., 2023). Viewed through this lens, citizen science participation is not merely an auxiliary or instrumental input to research but a constitutive element of knowledge production.

2.2 Co-design in citizen science

Citizen science, by definition, assumes citizen participation. However, the extent of participation differs significantly from project to project, and across different approaches to doing citizen science. In some citizen science projects, especially those initiated by citizens themselves, civic organizations or NGOs, citizens may actively shape the research topic, its methodology and activities, taking on the roles of co-researchers (Senabre Hidalgo et al., 2021). This is less feasible in projects initiated by professional researchers, where the principal investigators are often bound by project budgets and strict timelines and typically incorporate citizen participation within the broader research design. However, the actual forms of participation of citizens in the project may still be developed together with the citizens themselves, to ensure that participation is meaningful not only to the professional researchers but also the citizen scientists. This can be done through co-designing citizen science.

Co-design is historically based on the user-centred design of the 1970s. It maintains its emphasis on intentionality and reflexivity, which involves examining one's own assumptions, beliefs and judgements that shape one's understanding of an observed situation or environment. It differentiates from the other "co-concepts", such as co-creation and co-production (O'Donnell et al., 2025). The "co" in co-design" refers to collaboration, which conceptually rests on the premise that collective outcomes exceed the sum of individual contributions (Huxham, 1996). Unlike cooperation, co-creation, or coordination, which are based on a division of labour, collaboration requires the ongoing negotiation of different interests, values and power relations between those involved (Liburd, 2013). This conceptual distinction is particularly relevant for citizen science. A collaborative orientation shifts volunteers from being positioned as passive data gatherers to becoming active contributors to problem definition, methodological decisions, interpretive processes, and the use of findings. Collaboration can shape who has influence or who benefits from research, therefore it is not neutral: it can reinforce existing power differences or generate new forms of competition, especially when only a small inner circle is involved (Walsh and Kahn, 2010). Looking at power this way shows that people depend on each other, and these relationships are at once enabling and constraining (Elias, 1956). At the same time, these different perspectives, tensions and power relations can be productive, allowing collaboration to achieve results that no single person or organization could reach alone.

Design – the other part of "co-*design*" – is widely understood as a multifaceted practice that encompasses inquiry, meaning-making, intentional change, and social interaction. Scholars have described design as a form of reflective inquiry, as a conversation with the materials of a design situation (Schon and Wiggins, 1992), and as a cultural process through which meaning is constructed and negotiated (Heape, 2003; Krippendorff, 2005). Others emphasise design as purposive transformation, defining it as the deliberate shaping of preferred futures within conditions of uncertainty (Liburd, 2026; Nelson and Stolterman, 2012). Collaborative design, co-design, extends this orientation by framing design as a *shared*

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process of inquiry. New patterns of sense-making, sense-giving and "becoming something" arises as an evolving practice with others (Garner and Evans, 2012, p.xxiv). This perspective considers the social nature of collaborative practice, emphasising the complex, cultural and processual nature of human knowing, doing, making, relating, and organizing. Rather than simplifying the relational, ambiguous and negotiative processes involved, participants are encouraged to engage this complexity. By collaboratively exploring, revealing, and leveraging joint resources, novel or alternative syntheses of understanding are generated with which participants can identify (Liburd et al., 2022). Heape and Liburd (2018) argue that "co-designing with is the quintessential expression of an ethical, ongoing involvement of others through a respect for their ways of being in the world and their sense of values" (p. 231-232).

In short, co-design can be described as a methodology for exploring, understanding, and transforming present situations *with* others. It aims to ensure ownership of shared outcomes as they are negotiated synthesis of understanding that have been leveraged from individuals' variations of interpretation. Such methodological positioning contests the assumption that citizen science can be controlled to produce outcomes predetermined by professional scientists, or as required by funding agencies. It also underscores the need for inclusive methods, iterative protocols, explicit governance of power, and skilled facilitation to ensure that that different kinds of knowledge can be used, and that everyone feels a sense of ownership of the results.

3 Co-designing citizen science in the ISOSCAN project

In the ISOSCAN project, co-designing citizen science took the form of an iterative process involving several phases. The general structure of the process, illustrated in Fig. 1, was established in the grant application. It proposed that citizen science activities should help "overcome the lack in spatiotemporal water isotope data in Scandinavia" and that this would be achieved, at least in part, by collecting physical "surface snow and water samples". It also identified three key groups of participants: the project team (professional scientists); local and non-local recreational nature users (hikers, skiers, etc.), who would be prospective citizen scientists; and local nature and outdoor organisations whose employees and customers could also be prospective citizen scientists. The area around the city of Tromsø in northern Norway was chosen for the citizen science activities due to long-lasting seasonal snow cover, a local population that engages in many outdoor activities, and the fact that the region has recently become an important tourism hot spot. The iterative co-design process shaped how the citizen science activities would unfold, how they would be organised, and who would be involved.

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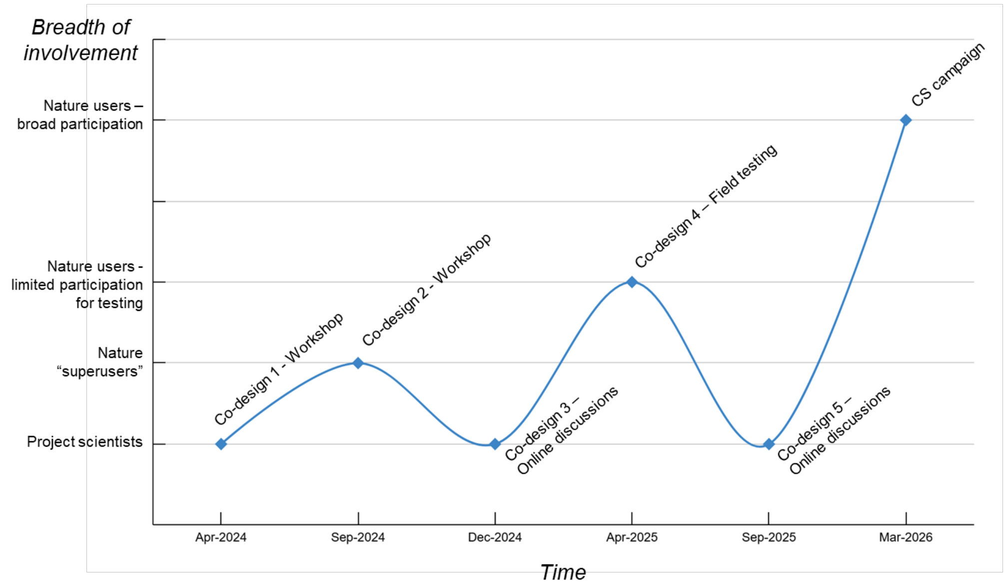

Figure 1: Conceptual sketch of the iterative citizen science co-design process in the ISOSCAN project.

Figure 1 illustrates how the co-design activities varied in the extent of participant involvement over time. These activities draw methodological inspiration from design charrettes, which are intensive, time-bound, and highly collaborative workshops that bring together diverse stakeholders to generate, test, and refine ideas iteratively. As Roggema (2014) notes, charrettes create a structured yet creative environment in which participants collectively explore problems, develop alternative solutions, and converge on shared directions for action. The first activity (Fig. 1, Co-design 1) involved only the multidisciplinary project team. The second activity, informed by the first, involved representatives of nature and outdoor organisations, tourism businesses, and locals in the Tromsø area (Co-design 2). We refer to these individuals as “nature superusers” to highlight their extensive knowledge of the local terrain and, more importantly, their in-depth understanding of local recreational practices in nature. The outcomes of these activities were brought back to the project team, who reassessed and reconfigured them for a prototype of a new sampling kit that included instructions and processes for citizen recruitment and communication (Co-design 3). This prototype was tested in the field with a limited number of recreational nature users (Co-design 4). The collected insights were subsequently used to reassess and reconfigure the approaches (Co-design 5) prior to a large-scale citizen science campaign. The sequence of activities in each workshop was purposefully chosen and systematically scaffolded in ways that support methodological replicability and avoiding predetermined outcomes (Duedahl, 2021).

Co-design 1 and 2 both played a pivotal role in defining the trajectory of the later activities as they served to surface participants’ initial expectations, interests and meanings. Both were conducted as in-person workshops centred on the

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co-design method of journey mapping. Journey mapping constitutes a strategic co-design method used to collaboratively capture and represent the trajectory of participants' experiences with a service, system, or environment from initial engagement through to subsequent interactions (Sanders and Stappers, 2014; Steen, 2013). Rather than serving as a simple chronological account, a co-designed journey map synthesizes participants' interactions, emotions and decision-making processes across multiple touchpoints through joint inquiry (Trischler et al., 2019). By visualizing experiential pathways, journey mapping makes visible the critical moments that shape meanings and values, and it offers distinctive vantage points from which stakeholders can identify, negotiate and reappreciate a given task to imagine what could be (Liburd et al., 2024).

During Co-design 1, a four-hour workshop in April 2024 at the Bjerknes Centre for Climate Research, University of Bergen, Norway, the project scientists were asked to generate water molecule journeys (Fig. 2). Scientists had to imagine and map how water travels from source to sink: where does the journey start, how is the water picked up by weather systems and lifted into the clouds? Some of the water falls as snow and is picked up by citizen scientists, ending up in a lab. Other water melts and returns to the ocean via rivers. One of the goals was to identify critical moments in the citizen science sampling process and to improve the sampling kit. The scientists' previous experience of using a professional sampling kit, which represented the ideal scientific procedure with its multi-step workflow and numerous materials, had proven to increase the likelihood of mistakes and seemed overwhelming to citizen scientists. Therefore, a redesign was necessary. Other goals of the co-design process were to address possible scenarios (Duedahl, 2021) and to identify relations between the multidisciplinary work packages. The first two authors facilitated and documented the process. Key findings were consolidated into reports distributed to the project group, thereby supporting transparency and sustaining collaborative engagement.

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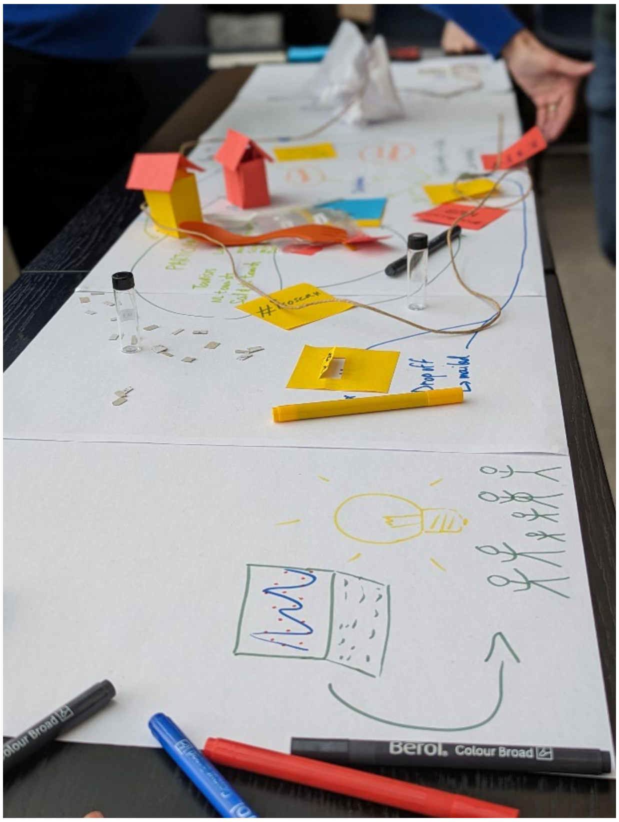

Figure 2: Journey mapping during the co-design workshop with the project team (Co-design 1).

In Co-design 2, eleven participants from outdoor and tourism organisations, as well as an international school responded to an open invitation to attend a workshop for a climate research project. The workshop took place in September 2024 at *Storgata Camping,* a centrally located venue in Tromsø. To situate themselves as co-designers, the consenting participants were first asked to reflect on a memorable day in the snow, and to imagine that they had collected samples as citizen scientists. This exercise extended beyond the journey itself to explore how they acted, who they were with, and what they valued. The central activity involved mapping their preferred sampling routes on a large physical map (Fig.3). This type of user journey mapping provides a structured way of eliciting and visualising participants' experiences as they navigate scientific tasks (Bonney et al., 2016). Using coloured yarn, participants visualised and pinned their routes, revealing potential sampling densities and suitable sample-kit pick-up points. Finally, participants reflected on the design of the sample kit, information feedback loops and possibilities for scalability.

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Figure 3: Journey mapping using a large map of Tromsø area during the co-design workshop with local "nature superusers" (Co-design 3) using coloured yarn to visualize and pin their routes, revealing potential sampling densities and suitable pick-up and drop-off points for the sampling kit.

By externalising tacit knowledge, the co-design activities helped participants articulate how they interpret scientific protocols, how they experienced moments of uncertainty or confidence, and how they perceived their role within the broader scientific endeavour. This process enabled participants and researchers to jointly identify points of friction, such as unclear instructions or inaccessible tools, as well as motivational drivers and critical transitions in the participation lifecycle (Stickdorn et al., 2018). At the same time, it supported ethical reflexivity, as both researchers and participants interrogated assumptions embedded in existing systems to collaboratively imagine alternatives (Steen, 2013).

4 Data and method: Using vignettes

Following the field test of the citizen science prototype (Co-design 4), a qualitative research process was initiated to evaluate the experiences of geoscientists involved in the co-design process. This process was led by the first two authors, whose disciplinary backgrounds lie in the humanities and social sciences. In May 2025, the other members of the author group, including hydrologists and meteorologists, were asked to reflect on situations that had arisen during the first year of the ISOSCAN project, which had attracted their attention, resonated with their experiences, or produced moments of tension. They were each asked to write this up into a vignette – a short textual narrative, description, story, or a snapshot relevant to the issues in question (Heldbjerg and van Liempd, 2018). Vignettes are highly adaptable in terms of both content and methodological application. They may draw on fictionalised scenarios or specific moments of fieldwork. In the context of this study, vignettes were used to produce a single, analytically oriented narrative that contained the complexity of an

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experience related to the co-designed citizen science. While the humanities and social science researchers in the project did not contribute vignettes, they engaged in comparable processes of reflection and adjustment.

As a result, five vignettes were written by the scientists specifically for the purpose of this paper but written without prior knowledge about details of how they would be used. This format was chosen to provide a structured means of articulating professional perspectives by exposing micro details of interaction, and to offer personal narratives containing reflections and observations that might not be openly and explicitly shared in a professional setting. For the purpose of the analysis, only the first two authors had access to the vignettes. The quotes in this paper are provided in anonymised form and analytic traceability is maintained by consistently referring to the author vignettes as Contributors 1–5.
The vignettes were analysed using reflexive thematic analysis following an iterative, data-driven approach (Braun and Clarke, 2021). Coding was conducted manually to ensure close interpretive engagement with each vignette. Manual coding supported sensitivity to nuance and contextual detail, enabling themes to emerge inductively from the focus and situated complexities of the vignettes (Braun and Clarke, 2021, 2023). Initially, the first two authors independently read the material several times to identify key patterns. Through these repeated readings, they noted both explicit content (semantic codes) and underlying themes or tensions (latent codes) that captured important actions, processes, and meanings within the vignettes. These codes were then compared, refined, and grouped into four preliminary themes. These themes were reviewed against the full set of vignettes and reduced to three final themes: navigating epistemic tensions, challenging own assumptions through mutual learning, and from control to trust. The findings are detailed in the following section.

5 Findings: project team perspectives on co-designed citizen science

In the five ISOSCAN vignettes, the scientists refer not only to their involvement in citizen science, but also to the co-design process and the broader challenges of interdisciplinary collaboration. All three aspects are closely related. The interdisciplinary assemblage of the project team was largely a consequence of integrating citizen science into the research design, with co-design introduced to facilitate a more robust and coherent incorporation of citizen-science activities. Moreover, the five vignettes surfaced interrelated issues of epistemology, mutual learning, and trust. Each warrants deeper examination to understand how geoscientists interpret, negotiate, and ultimately make sense of the complex realities of co-designed citizen science.

5.1 Navigating epistemic tensions

The vignettes reveal a wide range of epistemological concerns, such as what constitutes knowledge, how knowledge is produced, and how expertise is negotiated in the citizen science context. Contributor 3 notes: "*I see somewhat competing goals within the project that may not be fully reconcilable. On the one hand, the aim is to advance natural science modelling work. On the other hand, there is a strong focus on engaging citizen scientists in inclusive and meaningful ways*".

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Contributor 5 also highlights the contrast between the interests of scientists and non-scientists: "*From a scientific viewpoint, it was clear that the ideal sampling kit would capture the most comprehensive and highest-quality data possible*", and emphasising the fragility of data integrity: *"Any additional water input or loss during handling could alter this information, potentially leading to misinterpretations of the data"*. These reflections represent a scientific epistemology centred on precision, control, and traceability, and the anxiety that arises when these conditions cannot be guaranteed.

Still, science is not purely objective nor static. Contributor 2 observes: "*Based on our previous experiences and discussions with water isotope experts from institutions around the world [...], conversations within our project team, it became clear that snow sampling is not straightforward. There isn't a standardized sampler or method, and different researchers use various tools to collect snow samples depending on their specific research questions*". The citizen science context exposes the limits of disciplinary assumptions, including the subjectivity of impact and management of uncertainty. Contributor 3 clarifies: *"There can be different expectations regarding outcomes, impact and what counts as progress"*, continuing: *"How to best achieve this goal is somewhat subjective. What constitutes meaningful impact depends on perspective"*.

Recognising divergent epistemic interests becomes a source of frustration as the success of a citizen science project hinges on addressing all, even when they conflict. The geoscientists also point out that this situation is not unique to citizen science. Differences in epistemological approaches are present within scientific communities, and learning to navigate them is integral to scientific collaboration. In both contexts, the coexistence of multiple epistemic interests can be challenging. Yet it also creates productive tensions for methodological innovation, further addressed below.

5.2 Challenging own assumptions through mutual learning

Confronting one's own assumptions manifests through mutual learning across several dimensions. Scientists learn from citizen scientists, from each other, and from the constraints of real-world practice. In the co-design activities, negotiations of understanding were mediated by material artefacts, including string, paper, tape, tables, and sticky notes. Contributor 4 reflects: *"We crowd around an empty table with coloured paper, pens, string and duct tape. The instructions are to trace the path from sample collection to the lab. As the path slowly starts to appear on the table, the 'travellers' begin to share their opinions, question decisions and suggest solutions."* The material setup becomes a shared representational space, and a shared language gradually develops. It enables interdisciplinary negotiations and collaborative thinking that transcends their individual and disciplinary assumptions. Field conditions extended this learning into embodied trial and error, as experienced by Contributors 2 and 5: *"Despite being designed to pierce through snow and ice, we could not push the sampler in far enough due to snow clogging up the sampler or the snow cover. We tried wiggling it and pushing down on it with our feet. This uneven pushing means that the snow core does not represent the different layers of snow, which could lead to erroneous interpretations"*. Contributor 2 confessed: *"We tried multiple times… The conclusion was that snow sampling is a challenge even for 'expert' scientists."*

The co-design process itself was neither linear nor comfortable. Contributor 5, who joined the project later, offered a reflexive observation about its dynamics: *"My impression was that the extensive historical discussions around the*

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[sampling] kit design and the amount of time spent by the project members on this issue created a sort of anchoring bias, driving the discussion in circles and perhaps it was also not clear what the goal of the 'kit' was." Yet the process was not endless. As Contributor 4 noted: *"We are sharing ideas and values… finding consensus solutions together"* and Contributor 2 confirmed the practical payoff: *"Once the citizen scientists' feedback was taken onboard… the kit became much simpler to use."* The arc from what was perceived as a circular discussion to functional improvement illustrates how productive the discomfort eventually proved.

5.3 From control to trust

The citizen science approach used in ISOSCAN was not the usual way of conducting research. As Contributor 2 described: *"When I did the sampling myself in the previous project, I could oversee the process and ensure the quality of the sample from the field to the data analysis. Now, at a larger scale, with many scientists and citizen scientists, the sampling is done by others and is 'blind' to us"*. Trust emerged as a central concern: trust in collaborators, in citizen scientists, in data and in the co-design process itself. However, trust is as much a professional feature as an interpersonal one. Contributor 1 reflected on the first in-person meeting of the project team: *"I had the subtle feeling that what had, until that point, been somewhat non-physical assets in acquiring the necessary expertise for the project had suddenly become real, physical people. Of course, these people had their own personalities and experiences beyond the science they were going to be doing for the project"*. Building trust requires openness and vulnerability. Contributor 1 continued, talking about the project kick-off meeting:*"I talked about what had got me into science... maybe thereby revealing a real piece of myself, rather than presenting a glossy image, and finding common ground that way."* This set the tone for the round of professional introduction that noticeably shifted the conversation; it enabled a way for each to identify with their work package; to relate as human beings across disciplines; and with the overall project goals. Contributor 4 describes the workshop as a space where all voices matter: *"All are eager to listen, to adapt, to find a consensus… discovering what is important for each of us."*

As it was not feasible to have the same level of interpersonal contact with citizen scientists, trust had to be built with non-scientists in other ways. For example, Contributor 5 acknowledges the input from citizen scientists in designing the prototype: *"They disapproved of the use of plastic sample bags and spoons as they are wasteful and pose a high risk of polluting the environment."* It is noteworthy that trust with other scientists is established through interpersonal vulnerability and physical presence, whereas trust with citizen scientists is built through attentiveness to their values, interests, and situated concerns. These values and interests are seldom immediately apparent. However, the co-design activities and subsequent prototype testing contributed to making them more visible through carefully crafted prompts and through participants' interaction with the prototype. The interests of the non-scientists often came as a surprise to the scientists, and they were likely unknown to the non-scientists themselves prior to engagement with the project. This highlights the potential pitfalls of making assumptions about interests in advance. The overall need for openness and flexibility, but also the unease that comes with it was best described by Contributor 3: *"I've come to realize that within such a diverse group, there can be different expectations regarding outcomes, impact, and what counts as progress. […] I'm just a bit surprised that even with*

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good communication and relationships, we're still not fully aligned in our goals and expectations. But perhaps this is the nature of interdisciplinary work: navigating trade-offs and recognizing the value of multiple goals."

6 Discussion

Working with citizen science in geosciences is, by definition, a complex interdisciplinary endeavour since it involves combining geoscientific methods with the actions, experiences, and interpretations of diverse participants. Integrating insights from the social sciences and humanities is crucial for grasping how human activity constitutes a "dominant geological force on the planet" (Stewart, 2016, p.262). Nevertheless, such integration is still limited. A recent survey in Germany by Wiekenkamp et al. (2026, preprint) found that just over half of early-career researchers in the natural sciences had collaborated with fields outside the natural sciences. While this figure may be interpreted in different ways, collaboration across disciplines is needed to address complex societal challenges, such as climate change. Addressing this challenge may demand a more cohesive form of integration, commonly framed as convergent research (Finn et al., 2022). The scientists participating in this study highlighted this point, and the five vignettes collectively illustrate its relevance. These accounts also underscore that citizen science does not automatically result in effective interdisciplinarity. Rather, it makes inherent complexities and challenges more visible. Several of the ISOSCAN scientists expressed surprise at the difficulty of working across disciplinary boundaries, the perceived slowness of the process, and the need to reassess their own assumptions and practices. The iterative co-design process, however, created space to recognize and progressively integrate these differences into the subsequent research phases.

A key contribution of this paper is the identification of two forms of value for geoscientists engaged in citizen science co-design. The first form of value concerns inherent interdisciplinarity. The co-design process required not only time for mutual familiarization (Finn et al., 2022), but intentional cultivation of trust, exemplified by participants' sharing of their personal motivations for pursuing academic careers at the project's outset. These practices also enhanced professional motivation and curiosity, fostering a strong sense of shared ownership. Initially perceived as time-consuming, co-design prompted scientists to reflect on the limitations of existing approaches and their own epistemic assumptions. It encouraged a more active recognition of diverse knowledge systems, including those held by citizens, practitioners, and local or Indigenous communities, alongside scientific knowledge. However, it also highlighted diversity within scientific practice itself and underscored that scientists cannot ignore the human dimension of conducting scientific research (Frank et al., 2024). In this sense, co-designed citizen science not only transforms the research process but also the researchers involved. For the ISOSCAN geoscientists, its value therefore lay not only in enabling engagement across disciplines and with non-scientists, but also in making the challenges, assumptions, and possibilities inherent in such collaborations explicit and actionable.

These changes introduce the second dimension of value for geoscientists: the potential for epistemic innovation, understood as the generation of new forms of knowledge through the destabilisation of established and prevailing paradigms (Merz, 2018). From a geoscience perspective, the issues of data quality and knowledge validation remain salient when working with

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citizen science, and it may be unrealistic to expect citizen scientists to produce data that adheres to the strict evaluation criteria used in geoscience (Buytaert et al., 2014). At the same time, such criteria also delimit the kinds of environmental and human-environment knowledge that can be produced (Jaeger et al., 2023). While conventional science pursues objectivity through standardized methods and controlled conditions, citizen science can extend objectivity by broadening the empirical base and drawing attention to phenomena that may otherwise remain invisible to professional scientists (Bedessem and Ruphy, 2020).

In the ISOSCAN project, this became apparent through the development of the sampling kit, which turned out to be the element of the process that was both the most controversial and the most valuable. The final kit version differed substantially from the scientists' initial preferences, particularly with regard to methodological control and consistency. The new, reusable kit included a redesigned vial and simplified sampling instructions to avoid misunderstandings. It also included a feedback loop in the form of a designated online hub for sustained engagement with the citizen science participants, the ISOSCAN'ers. A negotiated co-design outcome, the kit became a unifying element for citizen scientists and professional scientists alike. Its simplicity and accessibility enabled a diverse group of contributors to participate. This supported the generation of additional data that would otherwise not be available to scientists, fully aligned with the initial motivation for engaging in citizen science. At another level, it opened new possibilities for working with highly distributed surface snow and water samples, illustrating how co-design can broaden both the scope and the nature of geoscientific inquiry. For geoscientists this demonstrates that, while co-designed citizen science may necessitate compromises in methodological control and working with a high degree of complexity and unpredictability, it can significantly expand empirical reach and generate new types of knowledge.

7 Conclusion

This article provides new insights on how geoscientists can make sense of co-designed citizen science. Based on the ISOSCAN project that aims to improve prediction models of hydrometeorological extremes in Scandinavia, conventional scientific observations were complemented by citizen scientists surface snow and water samples. Innovatively, the citizen science framework itself was co-designed by project scientists and non-scientific stakeholders, including prospective citizen scientists and representatives of local organisations, tourism and leisure businesses, and an international school. Co-design deliberately repositions citizen participation from an auxiliary input to a constitutive element of knowledge production, foregrounding how epistemic practices are shaped through interaction rather than imposed by disciplinary boundaries. Complexity theory deepens this insight by showing how scientific outcomes emerge from the dynamic relations among citizens, scientists, technologies, and environments.
The ISOSCAN project demonstrates how skilled facilitation and scaffolding of co-design methods can engage such complex relational processes that unfold when diverse actors collaborate. Illustrated in the five vignettes, co-design not only required

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geoscientists to navigate interdisciplinary terrains, but also created conditions in which established ways of knowing were productively unsettled. These conditions emerged through iterative collaboration, skilled facilitation, and new relational configurations between scientists and citizen scientists, which helped build trust and identify feedback loops. Tracing these processes exposes how co-design can operate as both a methodological and epistemic catalyst, expanding what geoscientific inquiry can attend to, how it can be conducted, and who can meaningfully participate in its production. The emergent formation of a community of ISOSCAN'ers, comprising both scientists and citizen scientists, reflects a broadly shared sense of project ownership. Complexity theory suggests that such ownership strengthens the relational feedback loops that underpin adaptive capacity (Mahmud et al., 2026). As Hartman (2023) shows, when actors assume ownership within a complex system of operation, they are more likely to adapt and sustain collaborative processes over time, an effect that, in the case of ISOSCAN, can only be confirmed as the project continues to unfold.

Cognizant of the study limitations of only involving five geoscientists and limited number of co-design participants in northern Norway, we contend that co-design in citizen science is not reducible to "hearing more voices" (Castelli et al., 2025). Mindful that decisions about who is included are never neutral, selecting participants and determining whose contributions count simultaneously exclude others from the collaborative space (Liburd, 2013). It highlights that the complex, relational dynamics of working with citizen scientists also introduce ethical concerns related to representativity, the democratization of science, and risks of epistemic injustice, all of which warrant future research. Addressing such concerns is crucial for building trust and ensuring that future citizen science initiatives are both participatory and capable of advancing geoscientific knowledge.

Data availability

The data analysed in this study consists of reflective narratives produced by the authors as members of the ISOSCAN research team. This data is not publicly available because it contains personal and confidential information that could compromise the privacy of the individuals involved.

Author contributions

Conceptualization: JL, KT and AEL. Investigation: all. Formal analysis: JL and KT. Writing - Original Draft: JL and KT. Writing - Review & Editing: all. Project administration: HS.

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Ethical statement

The ISOSCAN project was conducted in accordance with the ethical procedures and protocols of the participating institutions. The present study draws exclusively on reflections and narratives authored by the paper's authors and did not involve research participants beyond the research team. Consequently, no additional ethical approval was required.

Competing interests

The authors declare no conflict of interest.

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