

# From environmental observation to shared narratives through human-AI interaction

Luigi Ceccaroni<sup>1</sup> \*

Abigail Spyker<sup>2</sup>

<sup>1</sup> Earthwatch, Oxford, UK

<sup>2</sup> Northwest Media Collective, Vancouver, WA, USA

**Preprint.** This manuscript is currently under review. It has not yet undergone peer review.

**Version 1.** March 2026

\* Corresponding author: Luigi Ceccaroni, [lceccaroni@earthwatch.org.uk](mailto:lceccaroni@earthwatch.org.uk), +44 7384 724384

## **Keywords**

Human-AI interaction, environmental stewardship, citizen science, narrative agency, sustainability education, AI in education

# Abstract

A structural bottleneck limits sustainability practices: many people can participate in environmental observation, but far fewer can participate in the synthesis work that turns observations into shared narratives that guide action. We term this disparity "synthesis inequality". Citizen-science programs have expanded public access to data collection, yet data interpretation largely remains concentrated within scientific institutions. Local communities therefore generate observations but often lack the infrastructure to translate them into coherent narratives for decision-making. This paper introduces the AIRE framework, a structured approach to human-AI interaction designed to expand participant-led synthesis while protecting human agency. AIRE operationalizes a relational cycle of four phases (Connect, Reflect, Create, Share) in which generative AI functions are separated into bounded roles that support relational continuity, psychological safety, and synthesis assistance without displacing human interpretive authority. The theoretical foundation draws on polyvagal theory, the zone of proximal development, productive failure, and self-determination theory to establish physiological and developmental preconditions for reflective engagement. Social guardrails, including interrogative scaffolding, modular co-creation interfaces, and human facilitation protocols, ensure that the AI amplifies rather than replaces human meaning-making. The framework is grounded in established data governance principles (OCAP and CARE) and advances operational sovereignty as a practical standard for community control over data, narratives, and attribution. The paper presents testable hypotheses linking framework participation to narrative agency, emotional connection to nature, and intergenerational belonging, and proposes longitudinal methods for empirical validation.

# Introduction

Despite unprecedented access to environmental data and monitoring tools, the gap between ecological knowledge and sustained pro-environmental action persists. This access expansion has largely been driven by the rise of participatory models, most notably citizen science, which invite the public to contribute to large-scale data collection. While these models have democratized data gathering, they have not solved the deeper challenge of helping participants turn those facts into personal meaning. Evidence suggests that factual environmental knowledge alone accounts for only a small share of the variance in ecological behavior, whereas emotional connectedness to nature is far more strongly associated (Otto and Pensini 2017). A meta-analysis of 37 studies found a moderate, positive association between nature connectedness and pro-environmental behavior ( $r = 0.42$ ), a relationship that held across age group and geographic location (Whitburn et al. 2019). These findings imply that the bottleneck is not the availability of knowledge but the capacity to convert knowledge into the meaning, identity, and shared narrative needed for sustained pro-environmental action. Moreover, the format of information matters: recent economic research demonstrates that belief change driven by statistics decays by 73 percent within a day, while narrative-driven belief persists far longer (Graeber et al. 2024). The bottleneck, then, is fragmented observations and a lack of emotional connection.

This paper introduces the AIRE (Artificial Intelligence for Reconnecting with Earth) framework, a structured socio-technical approach that treats *generative AI* (GenAI) as a high-capacity linguistic and organizational force channeled toward participant-led synthesis.

## **The sociological context: disconnection, distress, and human-AI intimacy**

Environmental stewardship requires reflective capacity: the ability to move beyond reactive response toward meaning-making and considered action. Because this capacity depends on physiological states that determine whether reflection is available, any intervention aimed at participation and synthesis faces a practical design constraint. In U.S. national surveillance data, 39.7% of high school students reported persistent feelings of sadness or hopelessness in the past year, and 20.4% reported seriously considering suicide (Centers for Disease Control and Prevention 2024). Large-scale international surveys report high levels of youth worry about the environment and its impacts on functioning (Hickman et al. 2021).

Conversational AI is becoming a routine social technology. A 2025 nationally representative survey of U.S. teens (ages 13 to 17) reports that 72% have used AI companions, and 52% qualify as regular users (at least a few times a month). It also finds that 33% use AI companions for social interaction and relationships, including emotional support and friendship (Common Sense Media 2025). This widespread distress creates internal instability: chronic uncertainty activates defensive physiological states that compromise the reflective capacity required for stewardship. The AIRE framework addresses this challenge through its design for neuroceptive safety, the subconscious detection that an environment is safe enough to engage openly (see Section 2.1).

## **The structural bottleneck: synthesis inequality**

Environmental citizen science has expanded access to data collection, but data interpretation often remains concentrated within scientific institutions, even as some projects shift toward more reciprocal models (Hall et al. 2024).

We define Synthesis Inequality as a structural pattern in which people can contribute observations but cannot participate in interpretation, narrative construction, or the venues where those interpretations shape decisions. Until recently, synthesis required specialized training, dedicated time, and collaborative infrastructure concentrated in institutional settings. Many communities, therefore generate data but lack the means to translate fragmented observations into coherent narratives for local decision-making. When participation models exclude people from interpretation and narrative construction, they forgo the connectedness that most strongly predicts sustained ecological behavior (Otto and Pensini 2017). Excluding people from authorship and synthesis is both inequitable and behaviorally self-defeating.

## **The proposed framework**

To address these structural barriers, the AIRE framework is initially applied to youth populations, where identity formation is most fluid and where AI-mediated social relationships are already a baseline reality. By channeling these existing digital habits toward environmental connection, the framework facilitates a cycle that transforms lived experience into shared meaning. The framework moves participants through a structured progression: youth first connect through lived, place-based observation, then reflect to create space for emotional and cognitive sense-making, then co-author narratives with guided AI support, and finally share these outputs to consolidate identity and build community relevance.

To ensure the AI supports youth without taking over their creative voice, the framework establishes a strict governance boundary between the AI's assistance and the participant's authority. The framework enforces this boundary by limiting AI functions during each phase. While the AI adopts different roles, organizing data in one phase, suggesting phrasing in another, it is architecturally prevented from making final interpretations or determining the meaning of participants' experiences. During relational continuity, the AI remembers context, supports reflection, and sustains psychological safety. During collaborative synthesis, the AI helps organise observations into structured formats such as narratives, presentations, or advocacy pieces. A multi-layered architecture maintains human authority through social guardrails that limit the AI's role to support rather than authorship (see Section 3).

## **Theoretical foundations**

Research from neurobiology, developmental psychology, and social psychology underpins the AIRE framework. This section details the theoretical pillars that inform the framework's structure and explains how each shapes specific design choices.

### **Neuroceptive safety and the physiological prerequisite for learning**

The framework rests on a foundational principle: learning and connection become far less accessible in defensive states. Drawing on Polyvagal theory (Porges 2022), AIRE builds upon the concept of neuroceptive safety. When the nervous system detects a threat, defensive autonomic states prioritize survival, limiting access to the higher-order cognitive processes required for social engagement, creativity, and learning.

A safe relational container therefore serves as a physiological prerequisite for the framework's goals. Citizen science initiatives often rely on a "reporting" model, in which participants are asked to submit objective data points, such as species sightings or rainfall measurements, to centralized databases. While efficient for data collection, this model often fails to capture the subjective meaning of these observations. Furthermore, for many youth, contributing to environmental discourse is hindered by a psychological barrier: a state of persistent background anxiety born of chronic environmental uncertainty and "eco-anxiety." In this state of persistent stress, the brain prioritizes safety and social conformity, where participants submit raw data points to a database without further engagement.

To bridge this gap, the AIRE framework introduces a relational infrastructure designed to downregulate this hypervigilance. Rather than a neutral data-entry tool, the AI functions as a non-judgmental interlocutor that validates participants' input without penalizing them for sounding unscientific. The framework treats chronic stress and uncertainty not as a special clinical case but as a pervasive condition for youth navigating ecological instability.

This constant alertness prioritizes immediate safety and social conformity over the reflective capacity required for stewardship. Consequently, it creates a high "barrier to vulnerability," where participants feel subconscious pressure to remain within safe, objective reporting rather than risk the subjective, personal interpretation necessary to build a deep emotional connection. By acknowledging this reality, the AIRE framework shifts the goal from mere data submission to a process that first settles the participant's nervous system, allowing them to move from passive observation toward active, authoritative authorship. By providing a persistent, predictable, and supportive presence, the AI enables participants to shift from a defensive posture into a reflective one, the prerequisite for moving beyond reporting toward narrative synthesis.

## **From cognitive offloading to productive struggle**

To ensure that AI builds human capacity rather than dependency, the framework applies Lev Vygotsky's concept of the Zone of Proximal Development (ZPD) (Vygotsky 1978). The ZPD is the developmental window where a task is challenging enough to require support but within the participant's eventual reach. Research on fading scaffolds demonstrates that gradually reducing instructional support builds the student's own interpretive work rather than providing answers (McNeill et al. 2006; Pea 2004). AIRE operationalizes this principle by designing the AI to support without supplanting human judgment.

The framework preserves productive failure (Kapur 2008). Productive failure keeps the student performing the core intellectual labor of meaning-making, developing genuine competence and autonomy. This approach aligns with Self-Determination Theory, which identifies autonomy and competence as core psychological needs required for intrinsic motivation and learning (Ryan and Deci 2000). AI that does the thinking for students may rapidly generate polished outputs, but it undermines the developmental process those outputs exist to serve. Instead, through back-and-forth dialogue, the AI can accelerate the creative process by illuminating diverse angles on the student's experience. The AI proposes options while the student justifies, selects, and refines.

Recent AI research empirically validates these principles. Yan et al. (2025) conducted a randomized controlled trial comparing students using passive AI agents (which respond to queries) with students using proactive AI agents (which use scaffolding questions). Students using proactive agents significantly outperformed those using passive agents on comprehension tasks, and these benefits persisted after the intervention was removed, indicating that learning rather than temporary performance gains was supported. Conversely, Gerlich (2025) found that frequent reliance on AI tools for cognitive tasks correlates with cognitive offloading, which degrades critical thinking. This occurs

because the user skips the essential 'struggle' of organizing their own thoughts, effectively outsourcing their judgment to the machine.

Furthermore, Martin and colleagues (2019) demonstrated that when material scaffolds (i.e., supports built into instructional materials, rather than provided by a human facilitator) fade, student performance declines unless human facilitators provide responsive, complementary support. As supports built into instructional materials were removed, students continued to succeed only when a human teacher provided responsive guidance; in a classroom where the teacher simply repeated the static prompts already in the materials, student performance declined. This finding underscores the necessity of trained human facilitators who provide adaptive support, a principle AIRE embeds throughout its process (see section 3).

### **Identity as a social act: narrative consolidation and circulation**

We construct identity through the stories we tell (McAdams 2001), stories whose meaning is realized through participation in the symbolic systems of a culture (Bruner 1990). The proposed framework recognizes narrative as a social act. Narrative formats outperform factual or statistical formats in predicting behavioral outcomes. Nakano and Hondo (2023) found that narratives evoked stronger emotional responses and produced significantly higher behavioral intentions than equivalent factual or statistical presentations.

Sharing narratives publicly serves as a mechanism for identity consolidation by triggering distinct psychological shifts depending on the audience. When youth organise their experiences into a story, the act of constructing that narrative helps them find meaning and make sense of their experiences (Pennebaker and Seagal 1999), a process that can consolidate environmental identity (Clayton 2003). Sharing this story with peers in safe, reflective settings produces a sense of relational belonging; peer witnessing transforms a private realization into a recognized social reality, anchoring the participant's identity in the present. In contrast, storytelling approaches in citizen science can enhance civic participation and social inclusion (Veeckman et al. 2023), a function we distinguish as sharing with broader publics to catalyze civic agency. In this way, sharing moves the participant from private reflection to public commitment and social influence.

People construct identity not only through peer witness in the present but by positioning themselves within longer temporal narratives. Research on significant life experiences indicates that environmental sensitivity is most often rooted in experiences with family members, teachers, and other adult mentors rather than peer interactions alone (Chawla 1998). When elders share place-based knowledge, and youth receive it, the exchange functions as a knowledge bridge that fosters intergenerational solidarity (Bell et al. 2025). This transmission of oral history does not merely convey facts. It situates the participant within a biocultural heritage: the transmission of ecological knowledge and cultural memory through oral histories, sustained across generations (Rollo 2025).

### **Embodied experience and cognitive ecology**

Direct, sensory encounters with the living world cannot be replaced by digital interaction. These experiences form the basis of an environmental identity: a sense of emotional connection to the nonhuman natural world that becomes part of how one defines oneself (Clayton 2003; Chawla 1998). Effective interventions, therefore, begin with lived, place-based experience, reflecting research showing that embodied connection, not abstract information alone, supports long-term stewardship.

This connection depends on active engagement, not mere exposure. Harvey et al. (2023) found that children who completed a daily gratitude exercise, identifying three positive observations from nature over five days, showed higher emotional connectedness to nature than those who wrote about any three things they noticed. Although the increase in connectedness had faded by the two-month follow-up, pro-conservation behaviors remained elevated. This pattern suggests that identifying and valuing positive experiences in nature can strengthen durable stewardship behaviors even when the initial emotional lift diminishes. Dedicated reflection phases operationalize this finding: participants do not passively receive information but actively process, name, and make meaning from their observations over time.

If stewardship emerges from 'identifying and valuing' specific positive experiences, as Harvey et al. (2023) suggest, then the framework must provide a mechanism for participants to prioritize what is personally significant over what is merely observable. This is achieved through **selective capture**, which ensures that the 'active processing' of nature is not diluted by an exhaustive, administrative need to record every detail. Selective capture draws on Bateson's (1972) 'economics of flexibility': the principle that healthy systems must preserve space for exploration rather than fixing every experience into a defined category. By intentionally leaving some observations unrecorded and some cognitive space unformalized, the framework reduces 'brittleness': the psychological rigidity that occurs when an experience is optimized too tightly for data collection. This approach acknowledges that not every reflection needs to become a narrative. By protecting this open space, the framework prevents the premature closure of meaning, preserving the flexibility necessary for a participant's interpretive voice to evolve over time.

## **The AIRE framework for human-led synthesis**

This section operationalizes these theoretical principles into a replicable process. The framework channels GenAI's cognitive and linguistic capacity to support human agency. The framework comprises a four-phase relational cycle, four AI interaction modes, essential human roles, and a core group of design principles.

### **The relational cycle**

Interaction unfolds through a four-phase cycle that moves participants (youth enrolled in citizen-science or environmental-education programs) from lived experience to social meaning. The cycle begins with the Connect phase, grounding participants in place-based observation through field notes, elder interviews, and sensor readings alongside existing sources such as historical archives

and community research. This experiential foundation provides material for the Reflect phase, where facilitators guide participants to articulate what they notice, feel, and wonder, establishing neuroceptive safety before reaching conclusions. In the Create phase, participants transition to co-authorship: the AI offers ways to voice their story, allowing them to test phrasings while maintaining ownership of meaning. Finally, the Share phase moves generated meaning into the social world through circulation to peers, community members, or decision makers, driving identity consolidation.

Across the cycle, the GenAI system operates in different interaction modes depending on the phase, while remaining subject to the same constraints on interpretation and authority (see Table 1).

**Functional architecture: separated AI and human roles**

To ensure transparency, governability, and human control, the framework intentionally assigns essential human roles to scaffold AI functions, which are organized in two layers. The first layer is related to intimacy and attachment, and in this layer, the AI roles (Archive; and Mirror) focus on establishing the relational foundations of trust, continuity, and safety. The **Archive** role functions as a context-keeper, ingesting multi-modal inputs to maintain continuity across sessions. It remembers the participant's history, reducing cognitive load and ensuring interactions are cumulative and rooted in specific experience. This role supports operational sovereignty: the participant's control over data management, how narratives are managed, where outputs circulate, and how attribution is assigned. The **Mirror** role surfaces patterns and returns participants' emerging ideas back to them, supporting self-recognition, emotional grounding, and the psychological safety needed for vulnerable interpretation. The second layer is related to synthesis and meaning-making, and in this layer, the AI roles (Co-creator; and Translator) assist with the intellectual labor of creation while preserving human authority. The **Co-creator** role engages the participant in back-and-forth dialogue and helps surface diverse interpretations and potential phrasing, providing material the participant can test and shape. This design reflects experimental findings that creative self-efficacy is preserved when humans initiate creative direction and use AI for iterative feedback, but diminishes when humans merely edit AI-generated drafts (McGuire et al. 2024). The participant evaluates options and makes the final meaning-making decisions while sustaining the cognitive effort required for deep learning. The **Translator** role reformats participant-authored narratives for use in institutional settings. By rendering local knowledge into legible outputs such as policy briefs, grant narratives, or community reports without displacing authorship, it enables community insights to circulate in spaces of power.

**Table 1.** How AI roles support each phase of the AIRE cycle

<b>Relational phase</b>	<b>AI role</b>	<b>Primary design logic</b>
<b>Connect</b>	Archive	Establishes continuity and reduces predictive uncertainty.
<b>Reflect</b>	Mirror	Surfaces patterns and returns participants' emerging ideas back to them.

Relational phase	AI role	Primary design logic
<b>Create</b>	Co-creator	Helps participants move from raw ideas to a clear narrative.
<b>Share</b>	Translator	Renders outputs usable in institutional settings while keeping interpretive control with the community.

Human roles (Facilitator; Elder and Knowledge Holder; and Peer) in the AIRE framework are structurally essential. The separation of AI into bounded functional roles creates the conditions for human leadership, and humans should occupy that leadership for the framework to function as designed. The **Facilitator** role (teacher, guide, or program coordinator) carries primary responsibility for the integrity of the process. This role enforces boundaries around consent and sharing, prompts reflective inquiry that deepens meaning-making, and monitors for signs of cognitive offloading or emotional distress. The authors assume that the AI roles function as the support built into instructional materials: when they fade, participant performance declines unless human facilitators provide responsive, complementary support (Martin et al. 2019). The **Facilitator** role also governs the pace of progression through the phases, ensuring that participants do not advance from Reflect to Create, or from Create to Share, before they have completed the interpretive work required for each phase. The **Elder and Knowledge Holder** role grounds the work in lived and intergenerational knowledge. Elders and knowledge holders' participation transforms the cycle from an individual learning exercise into a transmission of biocultural heritage. When elders share place-based knowledge, and youth receive it, the exchange situates participants within longer temporal narratives that make stewardship an ethical inheritance rather than a momentary preference (Bell et al. 2025; Rollo 2025). The **Peer** role provides social reinforcement and collective witnessing that supports identity consolidation. During the Share phase, peer reception transforms private synthesis into public identity. The audience determines the function of this personal narrative: sharing with peers in safe, reflective settings consolidates identity in the present, while sharing with broader publics serves advocacy and social change (Veeckman et al. 2023).

Empirical studies suggest that relational AI interaction can increase environmental concern and pro-environmental intentions. Palomino-Gamez et al. (2025) report gains in pro-environmental behavior and environmental concern following narrative dialogue with a GPT-based agent. Pataranutaporn et al. (2025) likewise found that interactive agents outperformed static approaches in promoting sustainable intentions, with empathy emerging as a key design factor. However, their OceanChat (Pataranutaporn et al. 2025) did not shift psychological distance or policy support, a finding that may reflect the difficulty of altering deeper psychological constructs through brief interventions. AIRE addresses this limitation through cyclical engagement across all four phases, persistent memory that accumulates context over time, and facilitated identity consolidation through the Share phase with human witnesses.

## Design principles, safeguards and guardrails

The following set of core principles guides the framework's implementation and protects its purpose:

- **Bounded openness:** The framework encourages creativity and exploration within explicit constraints that protect psychological safety, integrity, and purpose. The facilitator and community norms establish these boundaries.
- **Human-led interpretation:** The AI assists with structure, organization, and translation, but humans define the final meaning, framing, and claims.
- **Selective capture:** The system preserves open-ended, exploratory space rather than formalizing every experience (see Section 2.4). In the Reflect phase, youth talk about what it felt like to be in a place and what stood out to them. In practice, a participant might share an observation during the Reflect phase that resonates emotionally but resists easy categorization. The AI does not pressure them to convert this into a data point or narrative claim. Some experiences remain uncommitted, available for future meaning-making or simply held as part of the participant's relationship with place. A few examples are as follows:
  - A student says: "When I walk past the old oak tree, I feel calmer, like it's watching over our street." That is an observation about a place and their body/emotion, but it is not an environmental-quality data point, and it does not neatly fit a category like "air pollution" or "tree health." Forcing them to label it as a specific variable ("what indicator is that?") would prematurely flatten the meaning.
  - After a field visit to a polluted canal, a student says: "It just smelled wrong, and I suddenly felt embarrassed that this is what visitors see first when they come to our town." This mixes sensory perception with shame and identity; we could code "smell" and "litter," but the important thing is the emerging story about how they see their community, which is not yet a clean "data point" or "narrative claim."
  - A student walking through a dried wetland says: "The ground sounded hollow when I stepped on it, and it made me think of something dying, but I don't know exactly what that means." Here, they notice a sound and have a strong association ("something dying") but cannot yet explain it scientifically or turn it into a clear argument.

In these situations, "selective capture" means the AI allows the student to hold onto that half-formed, affective observation without immediately demanding: "Is this about biodiversity loss or water scarcity? Turn it into a sentence for your story or a variable in your dataset." Some things are recorded loosely in notes or conversation, but are not forced into a schema or turned into a claim right away.

In the Connect phase, the participant might log "pH = 6.2, nitrate = X" (a classic environmental quality data entry). In the Reflect phase, the AI can ask, "What surprised you? What felt off, beautiful, or unsettling about being here?" and the framework allows those answers to remain messy, emotional, and partly uncategorized until the participant is ready to decide what they mean. So the design choice is to protect a zone where youth can notice, "This place makes me feel X because of Y," without having to immediately translate that into either a discrete measurement or a polished narrative.

To operationalize these principles, AIRE implements specific safeguards: facilitator oversight of AI interactions during program activities, participant control over data retention and deletion, and regular facilitator check-ins during Reflect and before Share to assess emotional well-being and interpretive autonomy. These mechanisms ensure that the framework remains accountable to both individual participants and the communities to which they belong.

In a context of collaborative synthesis, the AI helps organise observations into structured formats such as narratives, presentations, or advocacy pieces. This is achieved through an architecture where the authority remains with the human, thanks to social guardrails that strictly limit the AI's role to support rather than authorship.

The first layer of enforcement resides in the prompt architecture, which uses a method described as interrogative scaffolding. Unlike standard conversational models that might summarize a user's feelings or declare conclusions, the proposed framework's system instructions explicitly forbid the AI from making declarative statements about the user's experience. For example, instead of the AI telling a student that their observations of local wildlife indicate a deep concern for biodiversity, the system acts in a Mirror role to surface patterns and return the participant's emerging ideas back to them. The AI might note that the participant has mentioned specific changes in bird sightings several times and then ask what those changes mean to them, thereby ensuring the participant performs the intellectual labor of meaning-making.

A second layer of enforcement is embedded in the interface design and attribution management, intended to make cognitive offloading visible and difficult. The proposed framework's "Create" interface avoids a single "Generate" button for a full narrative and instead uses a modular process in which the Co-creator role provides diverse phrasing options based on the user's previous reflections. This design reflects the co-creation principle described in Section 3.2 (McGuire et al. 2024). Every sentence in the final output is tagged to maintain operational sovereignty, ensuring the participant retains control over how narratives are managed and how attribution is assigned.

The final and most critical layer is the facilitation protocol, which acts as a manual override and human-led gatekeeper for the entire process. AIRE treats the human facilitator as a structurally essential role because research on guided learning shows that participant performance declines when human support is withdrawn (Martin et al. 2019). This human oversight, combined with regular check-ins to assess interpretive autonomy, ensures that the AI's generative power is channeled toward human agency rather than dependency.

The following presents a sample interaction script from the proposed framework, demonstrating the **Mirror** and **Co-creator** roles in practice. This dialogue illustrates how the framework prevents the AI from leading the witness or generating meaning on behalf of the youth participant.

### **Phase: Reflect (the AI as Mirror)**

**Youth participant:** I spent an hour by the creek today. It's different from last week. The water is much lower, and the rocks look kind of chalky. It made me feel... I don't know, just sort of quiet and heavy.

**AI (Mirror mode):** I've recorded your observation about the lower water levels and the chalky appearance of the rocks. You described your internal state as feeling "quiet and heavy." If you look back at your notes from last week, you used the word "energetic" to describe the same spot. What do you think changed in the environment that shifted your feeling from "energetic" to "heavy"?

**Youth participant:** Last week, the water was rushing; it sounded different. Today, it's just sitting there. It feels like the creek is tired.

**AI (Mirror mode):** So the "heaviness" is linked to the lack of movement and sound compared to last week. If you had to explain to someone else why a "tired" creek matters to this neighborhood, what would you tell them?

---

### **Phase: Create (the AI as Co-creator)**

**Youth participant:** I want to write a story for the community board about how the creek is losing its voice because of the drought.

**AI (Co-creator mode):** That's a powerful central metaphor. Based on our conversation, I've pulled three ways we could start this narrative using your own words. Which of these feels most like what you want to say?

- **Option A (Focus on sensory change):** "A week ago, the creek was loud. Today, the water is low, and the rocks are chalky, as if the creek has grown tired."
- **Option B (Focus on the metaphor of voice):** "The rushing sound of the water is gone. Without its movement, it feels like the creek is losing its voice to the drought."
- **Option C (Focus on the observer's feeling):** "Standing by the creek today felt quiet and heavy. The water isn't rushing anymore; it's just sitting still."

**Youth participant:** I like Option B, but add the part about the chalky rocks from Option A.

**AI (Co-creator mode):** Understood. I've combined those. Here is the draft: "The rushing sound of the water is gone, and the rocks look chalky. Without its movement, it feels like the creek is losing its voice to the drought." Does it capture what you saw, or should we look for different words?

### **Ethical foundations: self-determination and operational sovereignty**

Principles of community empowerment and data governance provide the ethical foundation for the AIRE framework, ensuring that the technology serves as a tool for self-determination. The framework is fundamentally grounded in the *ownership, control, access, and possession* (OCAP) principles, which were originally established by Canadian First Nations to define how community data and information should be managed. By operationalizing OCAP, the AIRE framework ensures that the observations and narratives generated by youth can remain the property of the participants and their respective communities. This means the AI system does not necessarily "harvest" personal reflections for external model training or third-party use; instead, it acts as a private, secure archive where the community retains the absolute right to access and possess its own digital heritage. This technical sovereignty is a prerequisite for building trust, as it allows participants to share sensitive or raw environmental observations without fear of losing control over their intellectual and cultural property.

Building upon these structural rights, the framework aligns with the *collective benefit, authority to control, responsibility, and ethics* (CARE) principles originally established for indigenous data governance (Carroll et al. 2020), which extend the focus from the mechanical management of data to the broader purpose and social impact of their use. While OCAP defines who holds the data, the CARE principles guide how that data are activated to serve the common good. For instance, the principle of Collective Benefit is realized through the "Share" phase of the relational cycle, where individual reflections are purposefully transformed into communal narratives that advocate for local environmental action. The Authority to Control is embedded directly into the AI's functional roles, such as the Mirror and Co-creator, which are architecturally constrained to prevent the machine from asserting its own interpretations over those of the human participant.

Furthermore, the framework integrates the Responsibility and Ethics pillars by requiring a human facilitator to navigate the potential emotional complexities of environmental anxiety. This human-led approach ensures that the data are not just "processed," but handled with a sense of duty toward the participant's well-being. By adopting OCAP (First Nations Information Governance Centre 2014) and CARE (Carroll et al. 2020), AIRE moves beyond simple data privacy; it creates a governance structure where the "Responsibility" to the community and the "Ethics" of the interaction are as important as the code itself. In this way, the framework ensures that the process of turning observations into narratives is an act of communal empowerment that honors the values and future aspirations of the people involved.

By placing governance and interpretive authority firmly in the hands of the community, AIRE enables those most affected by environmental change to have a voice in how their observations are interpreted and used. Procedural justice requires that affected communities participate meaningfully in decisions concerning them (Schlosberg 2007). Extending this principle, AIRE ensures that communities not only contribute data but retain agency over the narrative context in which others interpret those data. Operational sovereignty specifies what this control requires in practice, including control over what data are retained, how narratives are translated, where outputs circulate, and how attribution is

assigned. Taken together, these principles inform a process that channels AI's power toward human agency and connection.

## **Discussion**

By operationalizing theories from psychology and neurobiology, the AIRE framework offers a pathway for transforming human-AI interaction. This section evaluates the broader implications, examining the potential to address systemic inequities in knowledge production, analyzing risks and mitigation strategies, and outlining an agenda for future empirical research.

### **Implications for democratic knowledge production**

The AIRE framework addresses synthesis inequality directly. Without specific infrastructure for community-led meaning-making, contributory science models can drift toward concentrating dynamics in which communities just provide data, and synthesis and interpretation remain controlled by scientific institutions (Hall et al. 2024). The barrier here is shaped by institutional norms and boundary work that determine credibility and epistemic authority (Mayes 2022). Decision-makers may dismiss a single voice as anecdote, but patterned observations across a community become data they recognize. The bottleneck is not knowledge itself but the infrastructure for aggregation.

This focus on synthesis is not merely principled; empirical research validates it. A systematic review of more than 100 citizen science studies found that while data collection alone produced some positive outcomes, projects that extended participation into data analysis, interpretation, and reporting demonstrated uniquely significant and broader gains across content knowledge, inquiry skills, and stewardship behaviors (Ballard et al. 2024). AIRE targets precisely this stage, democratizing access to the synthesis work that produces these outcomes.

AIRE proposes an alternative model built on operational sovereignty. By equipping communities with tools for synthesis and interpretation, the framework helps them build their own capacity to produce narratives. The Translator role is particularly critical as it empowers communities to control not just their data but also the narratives derived from it. By helping render local knowledge into forms that are legible in spaces of power, it ensures that those most affected by environmental change can participate authoritatively in interpreting and governing it. This capacity to bridge local knowledge and institutional power represents a fundamental redistribution of interpretive power, shifting from a concentrated to a more distributed model of knowledge production.

### **Theoretical boundaries, risks, and mitigation**

Implementing the AIRE framework carries risk. Three primary concerns are cognitive offloading, participant dependency, and facilitator variability. For example, in a global survey of sustainability educators from 45 countries, 51% identified hindering student learning as a challenge associated with

AI adoption (Leal Filho et al. 2025). AIRE treats this finding as a primary design constraint rather than a risk.

Gerlich (2025) finds that frequent reliance on AI tools leads participants to delegate cognitive processing to the machine, correlating with degraded critical thinking. Beyond this measurable loss of skill, AI-mediated recounting of experiences can flatten the phenomenological richness required for sustained identity formation (Joseph 2025), including the ecological self. AIRE mitigates this risk through specific design features: the Reflect phase precedes AI-assisted creation, ensuring participants engage in sense-making before receiving structural support; the Co-creator role surfaces options rather than generating finished drafts, a distinction shown to preserve creative self-efficacy (McGuire et al. 2024); and selective capture resists the pressure to formalize every experience. Together, these features subordinate AI efficiency to human meaning-making.

Any support system risks creating reliance that undermines autonomy. Yan et al. (2025) compared passive AI agents with proactive agents that used scaffolding questions similar to AIRE's Reflect phase. Participants using proactive agents significantly outperformed those using passive agents, and crucially, these benefits persisted after the AI was removed. This confirms that when AI scaffolds rather than solves, it builds capacities that remain in the person.

The framework's efficacy depends on skilled human facilitation. When material scaffolds fade, participant performance declines unless human facilitators provide responsive, complementary support (Martin et al. 2019). Inadequate facilitation (rigid adherence to prompts, premature progression through phases, failure to monitor for cognitive offloading) could undermine the outcomes AIRE aims to produce. This risk cannot be designed away; it must be addressed through facilitator training, observation, and accountability. By naming facilitation as structurally essential, AIRE makes the quality of facilitation a visible dimension of implementation.

## Testable hypotheses and future research

To move beyond anecdotal evidence, the AIRE framework must undergo rigorous testing. Because the framework is modular, separating AI roles from human facilitation, the authors propose a testing strategy that evaluates both the system as a whole and its individual components. This approach allows to identify not just *if* the framework works, but *which* specific mechanisms drive change. The following hypotheses are designed to guide future experiments and facilitate refinement of the AIRE architecture.

**The primary efficacy test (framework-level).** The first goal is to verify the core premise: that synthesis work is the missing link in stewardship.

- **Hypothesis 1:** Drawing on evidence that citizen science participation extending beyond data collection produces greater stewardship outcomes (Ballard et al. 2024), we hypothesize that participants completing the full AIRE cycle (Connect, Reflect, Create, Share) will demonstrate

significantly higher pro-environmental stewardship behaviors at a six-month follow-up than those engaged in data collection alone.

**Mechanistic tests (component-level).** These hypotheses aim to "stress test" the specific technical roles assigned to the AI. By isolating these variables, we can determine the value added by features such as memory and non-judgmental mirroring.

- **Hypothesis 2 (memory archive):** Drawing on evidence that narrative-driven beliefs persist significantly longer than statistically-driven beliefs (Graeber et al. 2024), we hypothesize that persistent memory functions (the AI's technical capacity to store, retrieve, and reference information across multiple separate sessions) will lead to higher participation adherence and more coherent narrative continuity compared to stateless interactions.
- **Hypothesis 3 (mirror):** Drawing on polyvagal theory's principle that perceived safety enables access to higher-order cognition (Porges 2022), we hypothesize that non-judgmental reflection will correlate with lower reported anxiety and greater willingness to revise personal interpretations of environmental data.
- **Hypothesis 4 (co-creator):** Providing options for the user to select and shape will preserve higher levels of creative self-efficacy than a system that generates full, ready-to-edit drafts (McGuire et al. 2024).

**The socio-technical synergy (human roles).** The necessity of the human elements integrated into the cycle must also be tested.

- **Hypothesis 5 (facilitation):** Gains in narrative agency will be significantly lower in settings with untrained facilitators or static prompts, underscoring the need for responsive human guidance (Martin et al. 2019).
- **Hypothesis 6 (intergenerational exchange):** Engagement with elders will produce narratives situated in longer temporal frames (referencing heritage and future generations) compared to peer-only groups (Chawla 1998; Bell et al. 2025).

The framework's overall efficacy is judged by its ability to cultivate three foundational capacities. First, **narrative agency**, the capacity to construct and revise one's own environmental story, is assessed by coding participant narratives for first-person interpretive claims and evidence of a distinct authorial voice. Researchers will look for a measurable shift in which participants move from merely reporting observations to actively making meaning of them. Second, **emotional connection to nature** is measured using validated instruments such as the Nature Relatedness Scale (Nisbet et al. 2008) or the Connectedness to Nature Scale (Mayer and Frantz 2004). These are administered at baseline, post-intervention, and follow-up to track internal shifts. Finally, **intergenerational belonging**, the sense of being situated within a temporal community, is assessed through narrative analysis of references to ancestors, elders, and future generations, capturing how the participant situates their work within a longer lineage of responsibility.

A mixed-methods design is essential to validate these claims, combining quantitative scales with qualitative analyses of narratives and facilitator observations. Longitudinal tracking is essential: outcomes must be assessed at a minimum of three time points (baseline, post-intervention, and six-month follow-up) to test the durability of stewardship identity.

To isolate the value of each component, we propose a five-arm comparison study. This design compares the (1) **full AIRE cycle** against (2) **data collection only**, (3) **AIRE without trained facilitation**, (4) **AIRE without intergenerational exchange**, and (5) **facilitated synthesis without AI support**. This rigorous multi-arm approach allows researchers to determine which elements are necessary, which are merely additive, and whether the AI provides unique value beyond what a skilled human facilitator can offer alone. These predictions establish a clear evidentiary standard for validating the framework.

## Conclusion

The central question facing society is not whether AI is good or bad for humanity, but whether the relational and social architectures governing its use are well-designed. Unconstrained, AI risks overwhelming human attention, flattening context, and eroding the processes of struggle and reflection through which we form meaning and identity. A well-designed architecture, however, can channel that same power toward human flourishing.

The AIRE framework offers one such architecture: a deliberate, theoretically grounded system that embeds AI within guided processes that prioritize relational safety, human-led interpretation, and the cultivation of durable capacities. By providing infrastructure for participant-led synthesis, AIRE creates a pathway in which technology amplifies the human observer's ability to make meaning. The framework's targeted outcomes (narrative agency, emotional connection to nature, and intergenerational belonging) are mutually reinforcing, forming the foundation of a durable stewardship identity.

# Declarations

## Funding

*The research described in this paper was funded by the European Commission via the ProBleu project, which has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101113001 and from UK Research and Innovation under the UK government's Horizon Europe funding guarantee, grant number 10082336. The opinions expressed in it are those of the authors and are not necessarily those of the ProBleu partner, the European Commission or the UK government.*

## Competing Interests

*The authors have no relevant financial or non-financial interests to disclose.*

## Author Contributions

*LC and AS conceived the framework. LC and AS developed the theoretical foundations. LC and AS developed the design principles and safeguards. Both authors contributed to writing and approved the final manuscript.*

## Data Availability

*Not applicable. This manuscript proposes a conceptual framework and research agenda and does not report a new empirical dataset.*

## References

Ballard HL, Lindell AJ, Jadallah CC (2024) Environmental education outcomes of community and citizen science: A systematic review of empirical research. *Environ Educ Res* 30(6):1007–1040. <https://doi.org/10.1080/13504622.2024.2348702>

Bateson G (1972) *Steps to an ecology of mind*. University of Chicago Press.

Bell E, Tremblay C, Carodenuto S, Downie B, Dearden P, Ole Kileli E, McDougall S (2025) Indigenous knowledge-bridging to support ecological stewardship in Canada and Tanzania. *People Nat* 7:1139–1150. <https://doi.org/10.1002/pan3.70034>

Bruner J (1990) *Acts of meaning*. Harvard University Press.

Carroll SR, Garba I, Figueroa-Rodríguez OL, Holbrook J, Lovett R, Materechera S, Parsons M, Raseroka K, Rodriguez-Lonebear D, Rowe R, Sara R, Walker JD, Anderson J, Hudson M (2020) The CARE principles for Indigenous data governance. *Data Sci J* 19(1):43. <https://doi.org/10.5334/dsj-2020-043>

Centers for Disease Control and Prevention (2024) Mental health and suicide risk among high school students and protective factors: Youth Risk Behavior Survey, United States, 2023. *MMWR Morb Mortal Wkly Rep* 73(Suppl-4):79–86. <https://doi.org/10.15585/mmwr.su7304a9>

Chawla L (1998) Significant life experiences revisited: A review of research on sources of environmental sensitivity. *J Environ Educ* 29(3):11–21. <https://doi.org/10.1080/00958969809599114>

Clayton S (2003) Environmental identity: A conceptual and operational definition. In: Clayton S, Opatow S (eds) *Identity and the natural environment* (pp. 45–65). MIT Press.

Common Sense Media (2025) *Talk, trust, and trade-offs: How and why teens use AI companions*. Common Sense Media. <https://www.commonsensemedia.org/research/talk-trust-and-trade-offs>

First Nations Information Governance Centre (2014) *Ownership, Control, Access and Possession (OCAP™): The path to First Nations information governance*. Ottawa: The First Nations Information Governance Centre.

Gerlich M (2025) AI tools in society: Impacts on cognitive offloading and the future of critical thinking. *Societies* 15(1):6. <https://doi.org/10.3390/soc15010006>

Graeber T, Roth C, Zimmermann F (2024) Stories, statistics, and memory. *Q J Econ* 139(4):2181–2225. <https://doi.org/10.1093/qje/qjae020>

Hall DM, Avellaneda-Lopez PM, Ficklin DL, Knouft JH, Lowry C (2024) Citizen silence: Missed opportunities in citizen science. *BioScience* 74(5):319–321. <https://doi.org/10.1093/biosci/biae020>

Harvey C, Sheffield D, Richardson M, Wells R (2023) The impact of a "Three Good Things in Nature" writing task on nature connectedness, pro-nature conservation behavior, life satisfaction, and mindfulness in children. *Ecopsychology* 15(1):26–35. <https://doi.org/10.1089/eco.2022.0014>

Hickman C, Marks E, Pihkala P, Clayton S, Lewandowski RE, Mayall EE, Wray B, Mellor C, van Susteren L (2021) Climate anxiety in children and young people and their beliefs about government responses to climate change: A global survey. *Lancet Planet Health* 5(12):e863–e873. [https://doi.org/10.1016/S2542-5196\(21\)00278-3](https://doi.org/10.1016/S2542-5196(21)00278-3)

- Joseph J (2025) The algorithmic self: How AI is reshaping human identity, introspection, and agency. *Front Psychol* 16:1645795. <https://doi.org/10.3389/fpsyg.2025.1645795>
- Kapur M (2008) Productive failure. *Cogn Instr* 26(3):379–424.
- Leal Filho W, Kim E, Borsatto JMLS, Marcolin CB (2025) Using artificial intelligence in sustainability teaching and learning. *Environ Sci Eur* 37:124. <https://doi.org/10.1186/s12302-025-01159-w>
- Martin ND, Tissenbaum CD, Gnesdilow D, Puntambekar S (2019) Fading distributed scaffolds: The importance of complementarity between teacher and material scaffolds. *Instr Sci* 47:69–98. <https://doi.org/10.1007/s11251-018-9474-0>
- Mayer FS, Frantz CM (2004) The connectedness to nature scale: A measure of individuals' feeling in community with nature. *J Environ Psychol* 24(4):503–515. <https://doi.org/10.1016/j.jenvp.2004.10.001>
- Mayes EC (2022) Citizen science and scientific authority: Have you checked the boundary work? *Citiz Sci Theory Pract* 7(1):42. <https://doi.org/10.5334/cstp.519>
- McAdams DP (2001) The psychology of life stories. *Rev Gen Psychol* 5(2):100–122.
- McGuire J, De Cremer D, Van de Cruys T (2024) Establishing the importance of co-creation and self-efficacy in creative collaboration with artificial intelligence. *Sci Rep* 14:18525. <https://doi.org/10.1038/s41598-024-69423-2>
- McNeill KL, Lizotte DJ, Krajcik J, Marx RW (2006) Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *J Learn Sci* 15(2):153–191. [https://doi.org/10.1207/s15327809jls1502\\_1](https://doi.org/10.1207/s15327809jls1502_1)
- Nakano Y, Hondo H (2023) Narrative or logical? The effects of information format on pro-environmental behavior. *Sustainability* 15(2):1354. <https://doi.org/10.3390/su15021354>
- Nisbet EK, Zelenski JM, Murphy SA (2008) The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. *Environ Behav* 41(5):715–740. <https://doi.org/10.1177/0013916508318748>
- Otto S, Pensini P (2017) Nature-based environmental education of children: Environmental knowledge and connectedness to nature, together, are related to ecological behavior. *Glob Environ Change* 47:88–94. <https://doi.org/10.1016/j.gloenvcha.2017.09.009>
- Palomino-Gamez S, Lis-Gutierrez JP, Henao-Rodriguez LC, Vazquez-Parra JC (2025) Environmental transformation in the classroom: Evaluation of a narrative GPT effect on university students' environmental awareness. *Int J Inf Learn Technol* 1–20. <https://doi.org/10.1108/IJILT-05-2025-0135>
- Pataranutaporn P, Doudkin A, Maes P (2025) OceanChat: The effect of virtual conversational AI agents on sustainable attitude and behavior change. *arXiv:2502.02863*.
- Pea RD (2004) The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *J Learn Sci* 13(3):423–451. [https://doi.org/10.1207/s15327809jls1303\\_6](https://doi.org/10.1207/s15327809jls1303_6)
- Pennebaker JW, Seagal JD (1999) Forming a story: The health benefits of narrative. *J Clin Psychol* 55(10):1243–1254.

Porges SW (2022) Polyvagal theory: A science of safety. *Front Integr Neurosci* 16:871227. <https://doi.org/10.3389/fnint.2022.871227>

Rollo MF (2025) Interconnected nature and people: Biosphere reserves and the power of memory and oral histories as biocultural heritage for a sustainable future. *Sustainability* 17:4030. <https://doi.org/10.3390/su17094030>

Ryan RM, Deci EL (2000) Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am Psychol* 55(1):68–78.

Schlosberg D (2007) *Defining environmental justice: Theories, movements, and nature*. Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780199286294.001.0001>

Veeckman C, Claes S, Van Audenhove L, van der Graaf S (2023) A framework for making citizen science inclusive with storytelling. *Front Environ Sci* 11:1211213. <https://doi.org/10.3389/fenvs.2023.1211213>

Vygotsky LS (1978) *Mind in society: The development of higher psychological processes*. Harvard University Press.

Whitburn J, Linklater W, Abrahamse W (2019) Meta-analysis of human connection to nature and proenvironmental behavior. *Conserv Biol* 34(1):180–193. <https://doi.org/10.1111/cobi.13381>

Yan L, Martínez-Maldonado R, Jin Y, Echeverría V, Milesi M, Fan J, Zhao L, Alfredo R, Li X, Gasevic D (2025) The effects of generative AI agents and scaffolding on enhancing students' comprehension of visual learning analytics. *Comput Educ* 234:105322. <https://doi.org/10.1016/j.compedu.2025.105322>