

Article

Reconceptualising the Nature of Science for a Flourishing Planet

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Abstract

Debates concerning the Nature of Science (NoS) have increasingly acknowledged its epistemic, cultural, ethical, and social dimensions. Recent scholarship has further foregrounded issues of equity, identity, and justice within science education. While these developments represent significant progress, this article argues that dominant conceptualisations of NoS remain fundamentally anthropocentric and insufficiently responsive to the ecological crises that define the Anthropocene. Drawing on Earth System Science, eco-centric theory, post-human theory and Indigenous and local knowledges, this paper proposes a planetary-conscious reconceptualisation of NoS. This framework retains the methodological rigour and evidential standards of Western science while expanding epistemic boundaries to include relational, place-based, and intergenerational ways of knowing. We argue that eco-centric and post-human theoretical frameworks offer essential pedagogical approaches for supporting young people to develop deeper connections with nature, fostering care-based relationships with the more-than-human world, and building resilience for sustainable futures. Such a reconceptualisation is necessary not only for scientific literacy but for the protection and enhancement of planetary health. Implications for curriculum, pedagogy, and teacher education are discussed, with particular attention to primary science education.

Keywords: nature of science; anthropogenic; ecocentrism; earth systems; indigenous and local knowledge; post-humanism

1. Introduction: Rethinking the Nature of Science in the Anthropocene

The Nature of Science (NoS) refers to the epistemology of science, encompassing the values, assumptions, and methods that underpin scientific knowledge production (Lederman, 2007; Erduran & Dagher, 2014). It includes understandings of how scientific knowledge is generated, validated, and revised; the role of creativity and community in scientific practice; the provisional but lasting nature of scientific knowledge; and the distinction between observation and inference, laws and theories (McComas, 2020). Traditionally, the Nature of Science has been understood primarily in terms of knowledge and reasoning—the reliability of scientific methods and the evidence underpinning claims. This epistemological framing has directly shaped science education, where the emphasis falls on mastering established facts and following prescribed procedures, projecting an image of science as objective, value-free, and methodologically alike. Less attention has been paid to the role of debate, creative thinking, and historical context in shaping what counts as valid knowledge. As a result, school science tends to present knowledge as fixed rather than as the consequence of human negotiation and inquiry. This risks alienating students who do not get the opportunity to experience and identify with the messy, creative, and deeply human story behind scientific discovery.



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The Nature of Science (NoS) is a broad and debated idea that covers how scientific knowledge is constructed, the ethics involved, and how science is shaped by culture and society (Rudolph, 2005; Erduran & Dagher, 2014; Allchin, 2020). Philosophical interpretations of science have been important in shaping these understandings. For example, Popper emphasised the tentative and provisional nature of scientific knowledge, arguing that scientific progress occurs through guesses and attempts to show that a theory might be wrong rather than the accumulation of absolute truths (Popper, 1963). In contrast, Kuhn demonstrated how scientific communities operate within shared paradigms that guide what counts as reasonable questions, methods, and explanations, and how these paradigms shift during periods of crisis and scientific revolution (Kuhn, 1962). Together, these perspectives establish science as both a rigorous, evidence-based endeavour and a culturally situated human activity. However, both frameworks share a foundational assumption that we believe requires review within the current polycrisis: they locate scientific practice exclusively within human understanding, community, and agency. In Lederman's widely applied beliefs of NoS, for instance, science is framed as a human endeavour shaped by human creativity and social processes (Lederman, 2007), where the natural world appears in this account as the object of human inquiry. Similarly, The Family Resemblance Approach (Erduran & Cheung, 2024) likewise frames science through human-centred categories; cognitive, epistemic, social and institutional, leaving non-human and material entities positioned as objects of inquiry rather than agents within it. This anthropocentric framing carries educational consequences: when science is taught as a purely human practice directed at a passive natural world, children may develop a sense of separation from, rather than embeddedness within, the systems they are studying. It is this structural assumption that the present article seeks to interrogate and, in part, to revise.

Over the past decade, science education research has increasingly connected NoS with questions of equity, social justice, and participation, challenging narrow portrayals of science as neutral, culture-free, and accessible only to a privileged few (Archer et al., 2015; H. E. Gandolfi, 2025). Such perspectives have expanded understandings of who can do science, whose knowledge counts, and who benefits from scientific activity, positioning NoS as not only an epistemic concern but also an ethical and political one.

These priorities are particularly urgent in primary science education, where foundational understandings of Earth systems, human–nature relationships, and scientific practice are first established. The ways in which science is framed for young learners, including what counts as scientific knowledge, how it is generated, and whose perspectives are legitimised, play a formative role in shaping children's early conceptions of the Nature of Science and, in turn, what it means to be scientifically literate. Early childhood represents a critical period for developing nature connection, ecological identity, and affective relationships with the more-than-human world (White et al., 2023), making primary science a key site in which epistemic understandings and relational orientations become intertwined.

This article argues that scientific literacy extends beyond the acquisition of disciplinary knowledge or procedural understanding of scientific methods. Rather, the conceptual frameworks and inquiry practices encountered in primary science shape not only how children come to understand scientific knowledge, but how they position themselves in relation to the natural world. When scientific literacy is framed narrowly, as the mastery of content and the application of empirical reasoning, children may develop technical competence while remaining relationally disconnected from the systems they are learning to describe and understand. When framed more broadly, encompassing systems thinking, ecological interdependence, and the social and cultural dimensions of scientific knowledge, scientific literacy may nurture a sense of belonging within planetary systems rather than an external observer or manager of them.

Evidence from climate change education research suggests that this broader, holistic orientation is central to scientific literacy. Students who understand the interconnected nature of environmental systems are significantly more likely to develop both the values and the intentions to act that meaningful climate engagement requires (Kroufek & Nepraš, 2023). The conceptual foundations laid in primary science therefore carry consequences that extend well beyond school, shaping the dispositions through which future citizens come to understand their place within, and responsibility toward, a rapidly changing planet.

Despite their transformative intent, such approaches, including the OECD's 2025 PISA science framework, which ambitiously reimagines scientific literacy through an 'Agency in the Anthropocene' lens (White et al., 2023), may not yet fully emphasise a more-than-human perspective. While these frameworks make meaningful strides toward environmental responsibility and future-oriented thinking, there remains an opportunity to further enrich them with relational, care-based engagement with the more-than-human world, moving alongside, rather than only in service of, the living systems of which we are a part. They focus on justice between humans while leaving the relationship between science, humanity, and the more-than-human world largely implicit. We believe this requires greater attention. Escalating environmental crises (climate change, biodiversity loss, water insecurity, energy transition pressures, and intensifying extreme weather conditions) push us to rethink what it means to be scientifically literate in the current times (IPCC, 2022, 2023). Current science education now operates within the context of the Anthropocene, where human activity is inseparable from Earth system processes and where scientific knowledge is being recognised as deeply connected with ethical responsibility, uncertainty, and unequal planetary impacts (H. Gandolfi, 2024; Ribeiro & Vasconcelos, 2025).

Evidence-based science, particularly as advanced through Earth System Science and climate research, has played a crucial role in documenting and communicating the scale of the planetary crisis, making visible the urgency of acting to prevent the worst impacts of climate change on Earth's biodiversity and life-sustaining systems (Schaeffer et al., 2025). The rigorous evidence base provided by disciplines such as atmospheric science, oceanography, and ecology has established with high confidence the anthropogenic drivers of planetary change and the consequences for Earth systems (IPCC, 2023). However, while this scientific rigour is essential for understanding the scale and causes of the ecological crisis, it is insufficient on its own for fostering ecological consciousness, relational understanding, and care-based action required for sustainable futures. This is where eco-centric and post-human theoretical frameworks become pedagogically important.

In response, we offer a planetary-conscious NoS as one possible framework for supporting teachers in this reconceptualisation, not as a definitive reframing, but as an invitation to think alongside the more-than-human world. Rather than replacing existing understandings of scientific knowledge, this pedagogical framework seeks to gently de-centre the human as the main perspective through which science is taught and understood, making space for relational, systemic, and ethical ways of knowing that extend beyond the human. Such a framework integrates:

1. The complexity of Earth System Science, supporting teachers to appreciate and teach the intimate relationships between lithosphere, atmosphere, hydrosphere and biosphere as interconnected, dynamic systems rather than discrete content domains (Metzger, 2024; Markwick & Strachan, 2025).
2. An eco-centric orientation that invites teachers to reposition humans as embedded within, rather than external to, natural systems and to consider what this means for how science is framed in the classroom;

3. Post-human perspectives that support teachers to decentre human exceptionalism and attend to the agency and entanglement of human and non-human actors in both scientific knowledge-making and in the living world their students inhabit;
4. The inclusion of Indigenous and local knowledges as rigorous, place-tested, and relational epistemologies developed over time—and as productive resources for expanding teachers’ and students’ understanding of what counts as scientific knowledge (Liboiron, 2021; Garrote, 2025).

Reconceptualising NoS in this way does not weaken scientific rigour, nor does it ask teachers to abandon the disciplinary knowledge that grounds their practice. Rather, it strengthens NoS by making explicit the assumptions, values, and relational responsibilities that already shape scientific practice. For teacher education, this reconceptualisation offers teachers a useful starting point for rethinking their practice, supporting young people not only to engage with science content and scientific enquiry, but to develop as ecologically literate, ethically responsive, and resilient participants in a rapidly changing world. It is important to note that this article is a conceptual and normative contribution. It does not report empirical findings but draws on theoretical frameworks and existing scholarship to propose a reconceptualisation of the Nature of Science. The authors acknowledge that this article is grounded in the opinion that science education must respond to the ecological crises of the Anthropocene. As such, it should be read as an argued position and an invitation to critical debate rather than as a neutral or empirical analysis. The framework we propose does not claim to replace existing NoS scholarship; rather, it seeks to explore it in response to the ecological crisis.

This article adopts a conceptual review approach. Literature was selected purposively rather than through systematic search procedures, drawing on literature across four intersecting fields: established NoS research, Earth System Science education, eco-centric and posthumanist theory. Sources were identified through the authors’ familiarity with these fields and through reference-chaining from key texts. Table 1 was developed iteratively, matching theoretical ideas with their pedagogical implications and concrete classroom examples. We acknowledge that this approach involves interpretive choices and cannot claim the comprehensiveness of a systematic review. The aim is not to resolve all tensions across these fields but to bring them together to articulate a coherent, provisional framework for reconceptualising NoS in primary science education.

Table 1. Framework for a Planetary-Conscious Nature of Science.

Dimension	Core Commitment	Implications for Interpretation of NoS	Pedagogical Commitment(s)	Primary Classroom Examples
Ontological	Humans as embedded within Earth systems and the natural world	Science studies systems we are part of, not as external observers	Relational and place-based learning: learners positioned as embedded participants in local ecosystems Pedagogies of care and hope: responding to learners’ affective relationship with the living world	Sitting quietly in the school garden and asking: “What do you notice? What notices you? What is different today?” Drawing yourself into the water cycle diagram and asking where you fit, then discussing what the standard diagram leaves out, e.g., how pollution enters and moves through the cycle, encourages children to see themselves as participants in, rather than observers of, Earth systems. Reflecting on how the class’s presence in the playground changes/influences it (the bee responds, the soil is compacted; seeds are spread on shoes)

Table 1. Cont.

Dimension	Core Commitment	Implications for Interpretation of NoS	Pedagogical Commitment(s)	Primary Classroom Examples
Epistemic	Knowledge as evidence-based and provisional	Claims are constrained by data, models, and uncertainty and so can be adapted	Systems thinking as core practice: reasoning across scales, exploring feedback and emergent properties Technologies and materials: how instruments, data, and models co-produce knowledge	Asking students to place one finger in warm water and another in cold water, then move both into water at room temperature, noticing that the finger from the warm water feels cold while the finger from the cold water feels hot and then using a thermometer to measure the actual temperature, prompts discussion about why our sense of touch is an unreliable instrument and why accurate scientific measurement tools matter. what question is each instrument answering?" Comparing what a hand lens reveals versus the naked eye and asking whether what we see through the lens is more real or just different Different tools (like AI) help us answer different questions. None tell the whole story: The AI says this picture is a fox, but we think it's a dog. What might the AI be using as evidence? What evidence are we using?
Systems	Earth as interconnected spheres—lithosphere, atmosphere, hydrosphere, biosphere	Feedback, scale, and non-linearity are central to explanation and understanding	Systems thinking: feedback loops, multi-scale interactions, emergent properties Relational and place-based learning: the local ecosystem as a place where Earth system relationships become visible and concrete	Taking a recent local event (a dry spell, a flood, an unusually hot week) and mapping effects across spheres: brown grass, puddles, cracked soil, fewer clouds, then drawing arrows to show which affected which. A class 'change wall' where children monitor both an evergreen and a deciduous tree over the course of a year, taking monthly photographs and recording averaged temperature, rainfall, and cloud cover, presenting this growing body of evidence on a working wall displayed along a corridor. Over time, children can return to this accumulating record and ask: 'Could these changes be connected? What might be driving all of them?' Longitudinal sit-spot practice: returning to one place each week across a term, recording what has changed and reaching for explanations that go beyond the school fence.

Table 1. Cont.

Dimension	Core Commitment	Implications for Interpretation of NoS	Pedagogical Commitment(s)	Primary Classroom Examples
Temporal	Deep time and historical inference	Scientific reasoning extends beyond direct experimentation and often includes using partial and non-direct evidence	Systems thinking: reasoning across temporal as well as spatial scales Technologies and materials allow scientists to read evidence from the past, making time itself a source of scientific data	Counting tree rings on a cross-section and asking what each ring “remembers” about the year it grew, connecting ring width to rainfall/weather records. Comparing historical photographs of the same local place (same street, same park, same creek) across decades and asking what changed and what might have caused it. A class rain gauge passed from year group to year group, with children reading their predecessors’ records and adding their own, developing a sense of data across time.
Ethical	Responsibility and care	Knowledge use has moral, cultural and ecological consequences	Pedagogies of care and hope: eco-anxiety, grief, and hope as rightful dimensions of scientific engagement Community-oriented action: scientific literacy as the basis for debate and stewardship	After investigating a local environmental change (a tree removed, a pond diminished), creating space for children to name how they feel, treating those feelings with respect, and encouraging thinking about interconnectivity of life. A class debate: “The council wants to pave this area for car parking. What do we know? Who is affected? What would we recommend?” Stewardship projects (planting, habitat monitoring, litter surveys) that are explicitly framed as the class acting on what it knows.
Epistemic Diversity	Multiple knowledge systems as epistemic partners	Indigenous and Western sciences are epistemic partners	Relational and place-based learning: local and Indigenous knowledges as resources for understanding place Technologies and materials: recognising that the tools we use to make knowledge, instruments, models, data systems, AI, are never neutral; they reflect ways of seeing and decisions about what counts.	Inviting a local farmer or allotment owner or long-term resident to share what they know about seasonal change in this place, then asking: “What were their instruments? What could careful watching across generations tell us that a rain gauge can’t?” Comparing a scientific ecological diagram of a local ecosystem with an Indigenous or cultural map, story, or account of the same place, and discussing what each makes visible and what each leaves out. For example, comparing a hydrological map of the River Thames with historical accounts, poems, or Indigenous-style oral histories about the river’s role in community life, identity, and meaning. Asking children: Whose knowledge of this place already existed before science arrived here?

Table 1. Cont.

Dimension	Core Commitment	Implications for Interpretation of NoS	Pedagogical Commitment(s)	Primary Classroom Examples
Justice	Uneven impacts and benefits	Science is situated within power and equity contexts	Community-oriented action and citizen science: foregrounding access, participation and equity (e.g., Rushton et al., 2025). Pedagogies of care: recognising that environmental harm falls unevenly, and creating space for children to notice, name, and respond to that unfairness.	Mapping which parts of the local area are most exposed to heat, flooding, or pollution, and asking who lives there, making the concept of uneven impact concrete and local. Discussing why some schools have nature gardens and some don't, or why some communities have clean water and some don't, and how science can help. Citizen science projects explicitly chosen because they address a question that matters to the local community, positioning children as knowledge producers whose work has real recipients.
Praxis	Collective and community action	Scientific literacy includes participation and drives planetary stewardship	Community-oriented action: citizen science and local stewardship as scientific practices Systems thinking: understanding collective action as operating within and upon complex systems	School biodiversity audits shared with the local council or community group, children experience science as something that informs action. Multi-year environmental monitoring passed between year groups, developing a school-level data record and a culture of collective scientific attention to place. Platforms where children present findings to a real audience (parents, local government, a community group) and field questions, scientific literacy enacted, not just assessed

2. Positioning the Nature of Science Through Earth System Science and an Ecocentrism

Earth System Science provides a powerful organising framework for rethinking NoS because it foregrounds the interconnectedness of the lithosphere, hydrosphere, atmosphere, and biosphere across interacting spatial and temporal scales ([Ribeiro & Orion, 2021](#)). While more bounded, knowledge-based science remains foundational to scientific progress and essential to predictive climate modelling, a systems perspective extends this understanding by accounting for the complex interdependencies, feedback loops, and long-term dynamics that characterise Earth's living systems, foregrounding complexity, non-linearity, and uncertainty as central rather than peripheral features of scientific explanation ([Feldbacher et al., 2023](#); [Sutinah et al., 2024](#)).

From a knowledge perspective, Earth System Science shows us how scientific understanding is built even when evidence is incomplete and outcomes can only be estimated in terms of likelihood. This is particularly relevant in areas like climate science and assessing natural hazards. ([IPCC, 2023](#); [OECD, 2024](#)). Geological science expands learners' understanding of NoS through deep time reasoning and inference from traces. Fossils, stratigraphy, and landscape change illustrate how scientific claims are generated through

interpretive frameworks constrained by available evidence rather than direct observation (Peppe & Deino, 2013).

In primary science contexts, Earth System Science can be approached through developmentally appropriate yet conceptually authentic investigations, promoting the ability for learners to make connections between rocks, soils, flora and fauna, thus linking geological and ecological knowledge. Young learners might examine local rock samples to infer past environments, noticing fossils embedded in limestone or the layered structure of sedimentary rocks found in the school grounds. They could observe erosion patterns after rainfall, developing initial understandings of how water shapes landscapes over time. Seasonal phenology observations, such as exploring when plants flower or when birds migrate, introduce children to the temporal rhythms of living systems and create opportunities to notice disruptions linked to climate change (Bright & Eames, 2022). Indigenous peoples across the world have long read and lived by such signs, encoding deep ecological knowledge of seasonal cycles, species behaviour, and landscape change into oral traditions, stories, and land management practices that span generations (McElwee et al., 2020). Bringing Indigenous ways of knowing into conversation with Earth System Science not only enriches children's understanding of ecological relationships but invites critical reflection on whose knowledge counts as science and how different knowledge systems can inform one another in responding to the planetary crisis. These explorations are not simplified versions of 'real' science. Instead, they allow children to genuinely engage with geological and ecological evidence. Through this work, young learners begin to use important scientific ways of thinking, such as looking at clues, making informed inferences about things that happened long ago, and understanding that scientists build knowledge by interpreting evidence, not by directly observing past events (Örnek & Yel, 2024).

3. Promoting Eco-Centric Pedagogies

An eco-centric orientation further reshapes the NoS by challenging implicit anthropocentrism in school science curricula. Eco-centric theory shifts the focus of value and concern from humans to ecosystems and ecological relationships, recognising the intrinsic worth of all living systems independent of their utility to human interests (Washington et al., 2017; Earth Charter Commission, 2020). This perspective does not deny human needs or agency; instead, it situates them within ecological limits and interdependent relationships. Knowledge, responsibility, and flourishing are understood as co-produced through interactions among human and non-human actors (Strachan & Markwick, 2025). This eco-centric repositioning is particularly powerful in primary science, where children's relationships with the more-than-human world are still being formed.

From such a perspective, science education becomes less about mastering nature for human benefit and more about understanding our embeddedness within natural systems and our responsibilities to them. This has profound implications for pedagogies: learning is reframed as relational engagement with place, organisms, and ecosystems rather than detached observation of 'natural resources'. Learners learn to see themselves not as separate from nature but as active participants in ecological communities whose wellbeing is inseparable from the health of broader Earth systems. Through inquiry, solution-focused activities and eco-centric pedagogies can, therefore, emphasise systems thinking, ethical thinking, interconnectedness, and the cultivation of ecological empathy, the capacity to understand and respond to the perspectives and needs of other-than-human beings and systems (Bell & Russell, 2000).

From such a perspective, the NoS is not just about how scientific knowledge is generated and applied, but about how that knowledge is situated within ethical and ecological relationships. This stance aligns with the need to expand our conceptual understanding of

the NoS to include values, positionality, and the consequences of knowledge use, particularly in relation to socio-scientific issues and environmental injustice (Dawson & Carson, 2020; H. Gandolfi, 2024).

4. Post-Human Theory and Science Pedagogies

This expanded conception of the NoS finds a powerful theoretical ally in posthumanism, which radicalises the relational and ethical dimensions of scientific knowing by fundamentally shifting the focus away from humans as the central to science. For primary science pedagogies, posthuman perspectives invite three important shifts in how children might learn about and with the natural world:

First, they encourage noticing how materials and tools shape discoveries. Rather than treating magnifying glasses, thermometers, or rulers as neutral equipment that simply reveals ‘what’s there,’ children can learn to recognise how these tools actively participate in creating knowledge and direct the types of knowledge that are created (Fenwick & Edwards, 2010). A magnifying glass does not just show a beetle; it flattens, distorts, requires stillness, and reveals ways of seeing while hiding others. When children explore questions such as ‘Does the magnifying glass change what we notice about the beetle?’, we support them to begin understanding that scientific knowledge emerges from relationships between learner, tool, and event.

Second, they can create space for recognising non-human agency and intelligence. Primary children can explore how plants ‘sense’ their environment without eyes or brains, turning toward light, growing roots toward water, or communicating danger to neighbouring plants through chemical signals (Trewavas, 2016). They might observe how fungi connect tree roots underground, sharing nutrients and chemical signals (Simard, 2026). These investigations move beyond seeing nature as passive objects acted upon by humans, toward recognising the more-than-human world as alive with purposeful action and communication. Questions shift from “What does the plant do when we give it light?” to “How does the plant sense and respond to light on its own?”

Third, they foster ‘response-ability’, the capacity to respond thoughtfully and ethically to the more-than-human world (Haraway, 2016). When children handle snails carefully during observation, return woodlice to their habitat after investigation, or decide whether disturbing a spider’s web to study it is justified, they practice recognising their relationships and responsibilities within multispecies communities. This moves beyond anthropocentric ‘kindness to animals’ toward understanding that human actions and non-human lives are reciprocal. Children develop ethical sensitivity to their partnerships with the more-than-human in everyday classroom encounters.

Posthuman theory does not dismiss scientific rigour. Instead, it encourages teachers and students to notice that what we call “rigorous” is always shaped by the tools we use, the environments we work in, and the social and cultural values around us. These factors influence what counts as valid evidence and whose perspectives are prioritised (Ross, 2021). By making these dimensions visible, post-human pedagogies strengthen scientific literacy by fostering epistemological humility, critical reflexivity, and understanding of how knowledge is always partial, positioned, and co-constituted with the material world (Barad, 2007; H. Gandolfi, 2024). Learners develop not only technical understanding but also relational sensibilities: the ability to notice, attend to, and care for the complex webs of dependence that sustain life.

Post-human theory provides a complementary lens for reimagining science education by decentering human exceptionalism and exploring the distributed agency of matter, technology, and non-human organisms in knowledge production (Barad, 2007; Braidotti, 2016). While eco-centric theory moves the focus from humans to ecosystems, post-humanism

challenges the traditional distinctions between humans and nature, culture and the physical world, and the observer and what is being observed, distinctions that have long shaped Western scientific thinking. Central to this perspective is the concept of entanglement: humans, technologies, organisms, and environments are not separate entities that interact, but are mutually constituted through ongoing interactions (Barad, 2007). Scientific knowledge, therefore, emerges not solely from human cognition but through material-discursive practices involving instruments, specimens, data, and environments. A microscope does not just show what exists, it influences what we are able to see and understand. When considering terminology, terms such as ‘agency’, ‘care’ and, ‘flourishing’ are used here in a pedagogical rather than literal claims. The ‘agency’ of plants, fungi or ecosystems does not claim that these organisms have intentions or consciousness in the same ways as humans. The aim is to shift how learners see the non-human world: from a passive object of study to a dynamic, responsive system that shapes what can be known and done within it. ‘Care’ and ‘response-ability’ (Haraway, 2016) are likewise used with ethical and pedagogical aims: they describe the capacity to attend to, and take responsibility for, our relationships within multispecies communities. They are not a claim that science and ethics are the same thing. ‘Flourishing’ is an ideal, not a measurement: it points to conditions in which both human and non-human life can thrive, and helps frame what this approach is for.

5. Bridging Western Science and Indigenous and Local Knowledges

A planetary-conscious NoS must also address the epistemic dominance of Western science and its historical entanglement with colonial extraction, environmental degradation and sociocultural injustices. Integrating Indigenous and local knowledges challenges the assumption that Western scientific methods constitute the only pathway to understanding the natural world.

Indigenous and Local Knowledges (ILK) are grounded in long-term, place-based observation and intergenerational knowledge transmission, including ecological knowledge and understanding of biodiversity and ecosystem processes (IPBES, 2022). They often attend explicitly to interdependence between land, water, sky, humans, and more-than-human life forms (Redvers et al., 2023). Importantly, these knowledges are not anecdotal or unstructured; they are empirically grounded, tested through lived experience over time, and constrained by ethical responsibilities to place and community (Liboiron, 2021; Rushton, 2024).

Integrating ILK into science education does not require abandoning rigour. Rather, it invites epistemic diversity: an understanding that different knowledge systems emerge from different purposes, methods, histories, cultural perspectives, and relationships with the natural world (Mavuru, 2022). Such diversity fosters epistemic humility within the NoS, enabling learners to recognise both the power and the limitations of scientific explanations and understanding. In primary science classrooms, this epistemic diversity can take several forms. Local Indigenous knowledge holders might be invited to share place-based observations of seasonal patterns, offering children access to knowledge systems developed through generations of careful attention to local ecosystems. In other words, it makes visible the values embedded in scientific questions, methods, and applications, as it reframes objectivity not as detachment but as accountable, reflexive practice (H. Gandolfi, 2024).

This connection is particularly valuable within Earth System Science, where long-term observation, pattern recognition, and place-responsiveness are central. It also addresses persistent inequities and narrow cultural representation in geological and environmental sciences by broadening whose perspectives inform responses for/to planetary change (Metzger, 2024). Crucially, decolonising the NoS strengthens rather than weakens scientific authority by making explicit how evidence, values, and power interact in knowledge production (H. Gandolfi, 2024).

6. Implications for Curriculum and Pedagogies in Primary Science: Toward Planetary-Conscious Science Education

Reconceptualising the NoS through more eco-centric and culturally diverse approaches will have significant implications for curriculum and pedagogical practice in primary science education. If science is understood as a relational practice embedded within Earth systems and co-constituted through human and more-than-human entanglements, then curriculum must move beyond fragmented topic coverage toward coherent progressions that support systems thinking and place-based inquiry (Ribeiro & Vasconcelos, 2025).

Early experiences: observing seasonal change, investigating soils, tracking water flow, experiencing plants grow: can support later understanding of Earth cycles, energy transfer, and climate processes, positioning the local environment as an authentic context for scientific inquiry (Örnek & Yel, 2024; Bright & Eames, 2022). Context-based inquiry aligns with NoS as practice: learners generate questions, interpret and reflect upon evidence, and revise explanations in ways that connect disciplinary concepts to lived experience (De Jong et al., 2024). From a post-human perspective, such inquiry becomes more than cognitive activity, it involves embodied, sensory, and affective engagement with material environments where knowledge emerges through direct encounter with soil, water, organisms, and atmospheric conditions (Duobliene & Vaitekaitis, 2021).

Five pedagogical commitments are especially relevant for fostering planetary-conscious scientific literacy:

1. **Systems thinking** must be treated as a core scientific practice, enabling learners to reason across disciplines and scales and to understand the interconnected causes of climate and biodiversity challenges (Demssie et al., 2020, 2023; Palozzi et al., 2024). This requires sustained attention to feedback loops, emergent properties, multi-scale interactions and uncertainty, rather than isolated cause-and-effect relationships.
2. **Relational and place-based learning** positions learners as embedded participants in local ecosystems. This eco-centric approach fosters direct and tangible engagement with natural systems and cultivates ecological empathy through sustained attention to the needs, rhythms, and responses of other-than-human beings (Russell & Bell, 1996; Kopnina, 2019).
3. **Pedagogies of care and hope** are essential. Emotion does not conflict with rigour; when thoughtfully integrated, it supports motivation, resilience, and ethical engagement with complex environmental issues (Pihkala, 2020; Orion, 2022). Recognising and working with eco-anxiety, grief, and hope enables learners to develop the emotional capacity needed for sustained engagement with ecological challenges.
4. **Attention to technologies and materials** that help learners understand how knowledge is co-produced through interactions with instruments, data, models, and environments. Post-human pedagogies invite critical examination of how tools shape what can be known and who benefits from structures of knowledge production (Barad, 2007; Fenwick & Edwards, 2010).
5. **Scientific literacy** must extend to community-oriented action (Dosemagen & Parker, 2019). Opportunities for deliberation, citizen science, and local stewardship position learners as contributors to shared knowledge and illustrate collaboration as fundamental to science (OECD, 2016; Kroufek & Nepraš, 2023).

We recognise that these expectations place considerable pressure on teachers who work within an education system largely built around human-centred priorities. However, as research highlights, sustained professional learning in Earth systems science, ecological literacy, and culturally responsive pedagogies is required if such curricular intentions are to be realised (Markwick & Reiss, 2024; Strachan & Markwick, 2025; Greer et al., 2025). Teachers require support not only in understanding eco-centric and post-human theoretical

frameworks but also in translating these into age-appropriate, curriculum-aligned learning experiences that honour both scientific rigour and relational ways of knowing.

7. A Planetary-Conscious Nature of Science: Conceptual Framework

To support theoretical clarity and practical application, the planetary-conscious NoS can be articulated as an integrated framework comprising eight aligned commitments (Table 1). We argue that together, these commitments reconceptualise scientific practice as relational, situated, and ethically consequential while retaining the methodological rigor of science and recognising the essential contributions of both Western scientific methods and Indigenous knowledge systems.

This framework positions the NoS not as a checklist of features but as a coherent orientation toward knowing and acting within a living planet. Scientific rigour is preserved through commitments to evidence, modelling, critique, and peer accountability while being enriched by relational and ethical dimensions too often made invisible in conventional scientific paradigms. The integration of eco-centric and post-human theoretical perspectives ensures that this framework attends not only to what we know about the natural world but also to how we relate to it, how knowledge is co-produced with material and more-than-human actors, and what responsibilities emerge from our entangled participation in Earth systems.

8. Tensions and Limitations

Any reconceptualisation of this scope must acknowledge the tensions and limitations it carries. Treating Indigenous and Local Knowledges as genuine partners must not slip into the claim that all knowledge is equal. This article does not argue that ILK and Western science are the same, only that they can work together, with each revealing different aspects of complex ecological problems. Harder questions remain important: how to distinguish well-grounded ILK (knowledge built up through long-term, careful observation of the environment, often across generations, that tracks real patterns in the world), who decides what belongs in the curriculum, and how to avoid tokenism. Those require further research and community-led deliberation beyond the scope of this article. Second, developmental appropriateness. Posthumanist and eco-centric frameworks carry a level of theoretical abstraction that may not translate straightforwardly into primary classroom practice. The pedagogical examples offered in this article are intended as illustrative starting points, not prescriptions. Further empirical research is needed to establish whether and how these frameworks can be meaningfully implemented with young children without either oversimplifying the theory or overburdening learners. Third, the framework proposed here places significant demands on teachers in terms of knowledge, confidence, and curriculum flexibility. We acknowledge that without sustained professional learning and institutional support, these expectations risk adding to already considerable pressures on primary teachers. The framework should be understood as an aspiration to work toward, not an immediate standard against which teachers are judged. Finally, the ethics of positioning children as planetary stewards. There is a real concern that framing young children as agents of planetary responsibility may place an unfair moral burden on them and risk instrumentalising their education for political purposes. We argue that planetary-conscious science education is not about burdening children but about giving them honest, hopeful, and scientifically grounded tools for understanding the world in which we hope they are able to thrive.

9. Conclusions

This article has argued that prevailing conceptualisations of the Nature of Science are no longer sufficient for an era defined by planetary instability. While recent NoS schol-

arship has productively engaged with social justice and equity, it has largely remained anthropocentric. By integrating Earth System Science, eco-centric perspectives, post-human theory and Indigenous and local knowledges, a planetary-conscious NoS can more accurately reflect how science now operates within complex, value-laden, and ecologically embedded contexts.

The proposed reconceptualisation retains the empirical rigour and evidential standards of Western science—recognising its essential role in demonstrating the urgency of climate action and understanding planetary processes—while expanding its epistemic and ethical horizons. It positions science as systems-based, situated, relational, and consequential—an endeavour that becomes inseparable from questions of responsibility, care, and planetary justice. Eco-centric and post-human theoretical frameworks are not alternatives to scientific rigour but essential complements that help young people develop the deeper understanding, emotional capacity, and relational sensibilities needed to care about nature, learn from the more-than-human world, and build resilience for sustainable futures.

In primary science education specifically, reconceptualising NoS offers a genuine opportunity to move away from the tendency to define it from an adult perspective and retrofit it poorly for younger learners. NoS should instead be understood as a concept that grows with the learner. Young learners are forming foundational understandings of what science is, who can do it, and what it is for during these critical years. By positioning science as relational, place-based, and ethically consequential from the earliest encounters, we support children in developing not only scientific literacy but planetary citizenship, seeing themselves as participants within the Earth, rather than seeing the Earth primarily as a reservoir of resources existing for human consumption, to be mined, harvested, commodified, and depleted in the service of human prosperity and economic growth. The experiences children have with rocks, soil, water, plants, animals, and weather in primary school shape their capacity for care, responsibility, and informed action as future adults navigating an uncertain planetary future. The proposed framework retains the empirical rigour of Western science while expanding its epistemic and ethical horizons, making visible the values, relationships, and consequences that have always shaped scientific practice but too often remain unexamined. In the Anthropocene, the question for primary science education is not whether to address sustainability but whether we will continue to frame science as a tool for human control and extraction or work toward reimagining it as a practice of understanding, belonging, and reciprocal care within Earth's shared and fragile systems. We argue that this latter orientation is both educationally desirable and scientifically defensible—not as a rejection of disciplinary rigour but as an expansion of what it means to be scientifically literate in an era of planetary crisis.

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Abbreviations

The following abbreviations are used in this manuscript:

NOS Nature Of Science

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