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Ho Yin Chan & Sibel Erduran

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The AI turn in science: a reflexive thematic analysis of scientists' commentaries and educational implications

Ho Yin Chan [a] and Sibel Erduran [b]

[a]School of Geography and Environment, University of Oxford, Oxford, UK; [b]Department of Education, University of Oxford, Oxford, UK

ABSTRACT

Background: Artificial intelligence (AI) is increasingly embedded in scientific research, reshaping how knowledge is produced, evaluated, and legitimised. While much existing research examines AI as a technical innovation or pedagogical tool, less attention has been paid to how scientists themselves articulate its role within science.

Purpose: This study examines how scientists discuss AI in *Nature* and *Science* commentaries and considers implications for the nature of science (NOS) and science education.

Sample: The dataset comprises AI-related commentaries published in *Nature* ($N = 242$) and *Science* ($N = 226$) between 2021 and 2024, covering scientific discourse both prior to and following the public release of ChatGPT in late 2022.

Design and methods: Data were analysed using reflexive thematic analysis (RTA), with the Family Resemblance Approach to NOS (FRA – NOS) as an analytical orientation. This study is among the first to combine RTA with FRA – NOS to identify cross-cutting patterns between epistemic, methodological, social, institutional, political, and value-laden aspects of science. Such combination is methodologically resonant with Wittgenstein's notion of family resemblance, foregrounding overlapping patterns of meaning rather than discrete categories.

Result: AI is not framed as a discrete tool but as a cross-cutting condition that reconfigures epistemic authority, infrastructure, scientific labour, governance, and public trust.

Conclusion: The analysis points to the importance of approaching AI in science education not merely as an add-on topic or technical skill, but as an opportunity to engage learners with science as a socially embedded, institutionally governed, and value-laden practice. Concrete examples are provided through educational applications of FRA – NOS. Methodologically, the study illustrates how combining RTA and FRA supports the identification of cross-cutting patterns that may be less visible in specific aspects of NOS or reliability-driven analyses.

KEYWORDS
Artificial intelligence; nature of science; family resemblance approach; reflexive thematic analysis; science communication

CONTACT Sibel Erduran Sibel.Erduran@education.ox.ac.uk Department of Education, University of Oxford, 15 Norham Gardens, Oxford OX2 6PY, UK

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Introduction

While scientific research has long been associated with processes of innovation and change (Kuhn 1962), recent advances in artificial intelligence (AI) have introduced new dynamics in how scientific knowledge is produced, evaluated, and communicated. Science education faces the challenge of preparing learners for participation in scientific work whose conditions, tools, and norms are increasingly in flux. Central to this task is fostering understanding of how science works and enculturating students into its practices (Berber et al. 2025). Responding meaningfully to this challenge requires more than tracking new technologies or updating curricular content; it also calls for attention to how changes in science are articulated, normalised, and taken up within scientific practice itself.

The rise of AI provides a particularly salient context in which this challenge becomes visible (Messeri and Crockett 2024). Although AI has featured in science education research for over a decade (Jia, Sun, and Looi 2024), its impact on formal school science remained relatively modest until around 2021 (Heeg and Avraamidou 2023). Since 2023, however, attention to AI has increased markedly across both scientific research and educational discourse (Almasri 2024). High-profile developments such as AlphaFold, named *Method of the Year 2021* for its role in protein structure prediction (Nature 2022), have contributed to this visibility. Yet a focus on discrete breakthroughs risks obscuring a more gradual reorientation that began around 2014, as AI moved from isolated applications toward a more embedded role in mainstream scientific inquiry (Bianchini, Müller, and Pelletier 2022; Van Noorden and Perkel 2023).

AI is now pervasive across scientific domains, from the natural sciences to the social sciences (Bail 2024), supporting activities such as large-scale data analysis, modelling, literature synthesis, and manuscript preparation. Rather than signalling a singular transformation, this proliferation raises a different set of questions: how is AI being accommodated within existing scientific practices, and how are familiar scientific concepts, such as evidence, explanation, trust, authorship, and responsibility, being used, qualified, or strained as AI becomes routine?

Despite growing attention to AI's technical capabilities and ethical risks, relatively little research has examined how scientists themselves articulate AI in relation to the epistemic, institutional, and value-laden dimensions of their work. Within science education research, the emphasis in applications of AI and generative AI (GenAI) has been rooted in pedagogical concerns as illustrated by some recent systematic reviews of the use of AI and generative in science education (e.g. Almasri 2024). Emerging research focuses on the development of learners' cognitive outcomes through the use of GenAI (Chiu 2023) and related themes such as data literacy (Qiao et al. 2024). GenAI tools are also positioned as instructional tools for teaching and teachers' preparation, including lesson planning (Lee and Zhai 2024). Educators recognize that GenAI tools like ChatGPT can answer questions, summarise information and facilitate peer collaboration (Lo 2023) as well as help with problem solving (Zhai, Nyaaba, and Ma 2024) and assessment (Zhai and Nehm 2023). The articulation of how AI is mediating scientific practice itself remains relatively limited (Erduran and Levrini 2024).

A particular angle through which science can be considered in the AI turn is through a closer examination of how scientists themselves are communicating about AI-mediated science. As a conceptual framework, a Wittgensteinian line of analysis suggests that AI often enters scientific practice in relatively ordinary ways, taken for granted rather than explicitly justified, shifting the philosophical focus from defining what AI is to examining how scientific language and practice continue to function when AI is involved (Chan and Erduran 2026). The present study extends this perspective by moving beyond close, situated description to examine how such articulations recur across a broad corpus of scientific discourse, and by considering the educational significance of these patterned ways of talking about and working with AI.

This analytic move is supported by Wittgenstein's notion of family resemblance, according to which concepts are held together by overlapping similarities rather than essential features (Wittgenstein 1958). In science education, this insight is present within the Family Resemblance Approach (FRA) to the nature of science (NOS), which conceptualises science as a constellation of interconnected cognitive, epistemic, social, and institutional dimensions (Erduran and Dagher 2014; Irzik and Nola 2014). In this paper, FRA is used heuristically to articulate how AI-related discussions cluster across multiple dimensions of scientific practice, rather than to explain scientific change or define a new essence of science. Importantly, scientists' narratives do not portray AI merely as a new tool, but as participating in the reconfiguration of how scientific work is coordinated, justified, evaluated, and governed. AI systems now contribute to hypothesis generation, data analysis and visualisation, text production, and decision-making, raising renewed questions about epistemic authority, accountability, professional roles, and trust. Rather than claiming that AI is comprehensively transforming science, this paper proceeds from a more modest premise: AI is already being lived with in scientific practice, and this situation warrants careful empirical and educational attention.

Accordingly, this paper addresses the following question: Given how AI is already being accommodated within contemporary scientific practice, how should science education respond? To guide the analysis, this question is elaborated through three interrelated sub-questions: (1) How do scientists discuss AI in commentaries published in *Nature* and *Science*? (2) Which dimensions of scientific practice (e.g. epistemic, methodological, social, and institutional) are invoked and combined in these discussions? (3) What implications do scientists' articulations have for science education?

To address these questions, we proceed in three stages. First, we review literature on AI and science that foregrounds cognitive, epistemic, social, and institutional dimensions of scientific practice. Second, we analyse scientists' commentaries on AI published in *Nature* and *Science* between 2021 and 2024, tracing recurring patterns in how AI is articulated across disciplinary domains and aspects of science. This analysis does not aim to stabilise meanings or explain causal change, but to identify patterns of emphasis that are educationally salient. Finally, we discuss the implications of these patterns for science education, extending existing educational (e.g. Ding et al. 2023) and ethical discussions (e.g. Borenstein and Howard 2021) to include sustained reflection on how science education might cultivate judgement, responsibility, and the capacity to go on appropriately within AI-inflected scientific practices.

Artificial intelligence and the reconfiguration of science

To understand how AI is reshaping contemporary science, it is important to situate AI not as a sudden disruption, but as a development that has become progressively embedded within scientific practice. This raises a familiar philosophical question: does AI merely change how science is conducted, or does it also rework the concepts through which science itself is understood and organised? This paper proceeds from the premise that AI does both. AI participates not only in transforming scientific activities, but also in reshaping the categories through which scientific work is interpreted, coordinated, and evaluated.

From a technological perspective, AI has developed through cumulative and incremental advances rather than abrupt breakthroughs. Symbolic approaches gave way to connectionist models, followed by machine learning, deep learning, and, more recently, large language models and generative systems. Contemporary tools such as ChatGPT or MidJourney are therefore better understood as outcomes of long-term developments in data availability, algorithmic design, and computational infrastructure than as singular technological ruptures. This gradual trajectory contrasts with popular narratives that portray AI as unprecedented or revolutionary.

At the level of public and professional discourse, however, AI has rapidly shifted from a specialised research topic to a pervasive feature of everyday life and scientific work (Cath et al. 2017). AI systems now mediate communication, creativity, evaluation, and decision-making, generating a widespread sense of acceleration. In this respect, the current moment resembles what Kuhn (1962) described as a paradigm shift: a transformation that appears abrupt precisely because the cumulative processes that enabled it recede from view. This perception of disruption can obscure the more subtle ways in which AI is absorbed into existing practices, norms, and institutional arrangements.

Conceptually, AI does more than introduce new tools; it unsettles how familiar scientific concepts are used. Historical analyses of technological change show that new technologies can reconfigure concepts such as agency, responsibility, or expertise, rather than merely modifying their interpretation (Löhr 2023). AI appears to operate in a similar way within science. Scientific authority, for example, is increasingly articulated across disciplinary boundaries. Where expertise was once closely tied to mastery within a clearly bounded field, contemporary scientific work often involves computational specialists operating at the intersections of physics, biology, medicine, and information science. Geoffrey Hinton's observation[1] that he does not clearly belong to a single discipline captures this blurring of scientific identities.

From a Wittgensteinian perspective, such blurring is not anomalous. Wittgenstein (1958) argued that concepts are not defined by fixed essences but by overlapping similarities across practices. Disciplines such as physics, chemistry, or AI are therefore better understood as evolving clusters of activities rather than stable conceptual containers. AI's integration into scientific work renders this fluidity more visible by extending scientific practices beyond traditional boundaries while retaining recognisable continuities.

Wittgenstein's "family resemblance" idea has been taken up in science education through the FRA to the NOS, an influential perspective in science education research and curriculum development over the past decade (Barak 2023; Baddour and BouJaoude 2025; Boven et al. 2026; Cheung et al. 2025; Erduran and Dagher 2014; Fricke and Reinisch 2023; Irzik and Nola 2014; Kaya et al. 2025; Pereira and Ha 2025; Takriti et al. 2023; Voss et al. 2023). FRA is philosophically grounded in Wittgenstein's notion of family resemblance, conceptualising science not as a unified entity defined by necessary and sufficient characteristics, but as a constellation of practices, values, and institutional arrangements held together by overlapping similarities. Erduran and Dagher (2014) extended this orientation into a comprehensive framework for science education, articulating interconnected dimensions of scientific practice, including epistemic aims and values, methods, knowledge, professional activities, social organisation, governance, and economic and political structures, which are understood as overlapping and mutually informing rather than discrete or hierarchical.

The growing prominence of FRA-NOS is reflected in a substantial body of empirical research examining assessment (Cheung 2020), textbooks (BouJaoude, Dagher, and Refai 2017), teacher engagement with NOS (Aksöz et al. 2025), science communication (Chan et al. 2023; Cheung et al. 2023) and specific dimensions such as scientific methods (Wei, Jiang, and Gai 2021) and social-institutional aspects of science (Akbayrak and Kaya 2020), as well as in a dedicated *Science & Education* special issue (Barak 2023). Importantly, FRA's non-essentialist and relational character makes it particularly well suited for examining AI in science. AI does not enter scientific work as a bounded technical innovation that can be located neatly within a single NOS aspect (Cheung et al. 2024). Instead, it is implicated simultaneously in epistemic judgement, methodological decision-making, professional roles, institutional infrastructures, governance arrangements, and public legitimacy.

As the empirical analysis will show, scientists' narratives about AI rarely confine it to one aspect of science. Instead, AI is discussed through entangled concerns involving judgement, infrastructure, labour, governance, and trust. Accordingly, FRA is used in this study not as a classificatory scheme to stabilise aspects of NOS, but as a heuristic orientation for articulating patterns across different aspects of NOS. Combined with reflexive thematic analysis, this approach supports a relational understanding of how AI is being made intelligible within contemporary scientific practice.

To examine how conceptual reconfigurations about different aspects of NOS are articulated by scientists themselves, the following section outlines the analytic orientation and methodological strategy used to study AI-related discourse across influential scientific forums of *Nature* and *Science* journals.

Methodological orientation and analytic strategy

Data sources

Review commentaries written by scientists were selected as the primary data source because they provide timely, reflective, and forward-looking accounts of developments within scientific practice. Commentaries published in *Nature* and *Science* are typically invited contributions from established researchers and undergo a shorter editorial process than full research articles. Unlike empirical papers, these texts are not required to present new data; instead, they provide space for scientists to reflect on emerging developments, articulate concerns, and anticipate future directions, often drawing on unpublished work, preprints, or ongoing research programmes.

This genre is well suited to the aims of the present study, which focuses not on evaluating the technical performance of specific AI systems, but on examining how AI is discussed, framed, and situated within contemporary scientific practice. Review commentaries frequently engage with methodological innovation alongside social, institutional, ethical, and political dimensions of science, including governance, responsibility, bias, and regulation. Because many AI-related developments cut across disciplinary boundaries, commentaries offer a vantage point for tracing patterns of emphasis that may not yet be stabilised within primary research literature.

Sample

The dataset comprises review commentaries published in *Nature* and *Science* between 2021 and 2024. This period was selected to capture shifts in how AI is discussed within the scientific community, particularly before and after the public release of ChatGPT on 30 November 2022. An initial search using the keyword 'Artificial Intelligence' identified 242 commentaries in *Nature* and 226 in *Science* that engaged substantively with AI. Together, these texts form a corpus suitable for examining how AI-related developments are articulated across scientific domains and how different aspects of scientific practice are foregrounded in scientists' narratives.

In contrast to systematic reviews that focus on empirical research articles (e.g. Almasri 2024; Heeg and Avraamidou 2023; Jia, Sun, and Looi 2024), this corpus enables analysis of discursive, institutional, and normative concerns alongside technical developments. It therefore supports an educationally oriented analysis of science as an enterprise, rather than an assessment of the effectiveness or accuracy of particular AI applications.

Analytic orientation

Building on the conceptual framing above, this study adopts the FRA as an analytic orientation rather than as a classificatory or explanatory framework. FRA is used here as a set of sensitising concepts that orient analytic attention to epistemic, social, institutional, political, and economic dimensions of scientific practice, without presuming that these dimensions can be cleanly separated or hierarchically ordered.

This methodological use of FRA aligns with its Wittgensteinian foundations, in which meaning arises from use within practice rather than from fixed definitions (Wittgenstein 1958). While Erduran and Dagher (2014) articulated FRA as a comprehensive framework for science education, these dimensions are not treated here as predefined coding categories. Instead, they provide a conceptual vocabulary for noticing how AI-related discussions span multiple, overlapping aspects of scientific practice.

This orientation is especially important given the character of the corpus. As the analysis demonstrates, AI is rarely discussed by scientists as a concern confined to a single NOS aspect. Treating the FRA categories as fixed analytic bins would therefore risk re-stabilising boundaries that the framework itself was designed to resist. Consistent with calls to treat FRA – NOS as dynamically interwoven (Chan 2025), this study uses FRA heuristically to trace patterns across different aspects of NOS rather than to allocate data to discrete categories.

Analytic method

Data were analysed using reflexive thematic analysis (RTA), following Braun and Clarke's conceptualisation of thematic analysis as a flexible, interpretive approach centred on researcher judgement, reflexivity, and theoretical sensitivity (Braun and Clarke 2021; Byrne 2022). Rather than treating themes as entities emerging from data, RTA was understood as an active process of meaning-making shaped through sustained analytic engagement. The analysis was informed by Braun and Clarke's (2006) six-phase framework – familiarisation, coding, theme development, review, definition, and writing – but these phases were approached as recursive and intertwined. Analytical work proceeded through continuous movement between the dataset, coding, thematic construction, and theoretical reflection.

Theme development and refinement occurred through ongoing cycles of interpretation and writing, ensuring coherence and conceptual distinctiveness. Coding remained fluid as insights developed, and no attempt was made to establish intercoder reliability, consensus, or saturation. Instead, researcher subjectivity was treated as an analytic resource (Cheung and Tai 2023), with rigour grounded in theoretical coherence, transparency, and explanatory power. Together, FRA and RTA enabled an analytic strategy that accommodates overlap, resists rigid categorisation, and remains responsive to the evolving articulation of scientific practice in an AI-mediated context.

Researcher positionality, analytic situatedness, and limitations

Our analysis is shaped by our positions as a cultural geographer and a science educator based in Europe, alongside prior engagement with the FRA – NOS. This shared grounding oriented the study toward understanding science as a heterogeneous, practice-based, and socially situated enterprise, while our disciplinary perspectives sensitised attention to different aspects of AI-mediated science. A geographical lens foregrounded material infrastructures, spatial inequalities, and geopolitical conditions, whereas a science education perspective emphasised epistemic practices, professional roles, and educational implications. These orientations informed how patterns and connections between epistemic, institutional, and value-laden aspects of FRA-NOS were interpreted.

The corpus reflects particular conditions of knowledge production. Commentaries published in *Nature* and *Science* are situated within Western, industrialised, and well-resourced contexts, and predominantly represent WEIRD perspectives (Haslam et al. 2024). This is treated not as a neutral feature of the data but as an outcome of publishing norms, institutional priorities, and disciplinary gatekeeping that shape which accounts of scientific change become visible and authoritative.

These conditions also delimit the scope of the study. The analysis is based on commentaries from two high-impact journals and therefore does not capture the full diversity of global scientific discourse. In addition, the interpretive nature of RTA means that findings reflect theoretically informed readings of how AI is articulated, rather than exhaustive or generalisable claims about scientific practice.

Positionality is thus understood as an analytic condition rather than a variable to be controlled. The study offers situated interpretations of how AI is discussed within influential scientific forums, and these interpretations are intended as analytically productive resources for thinking about science education rather than comprehensive representations of AI in science.

Results and findings

Corpus overview and analytic orientation

The dataset comprises AI-related commentaries published in *Nature* and *Science* between 2021 and 2024. As shown in Figure 1, there is a marked increase in AI-related discussion following the public release of ChatGPT in late 2022. Articles were grouped into three categories: those in which AI constituted a central theme (blue in the bar chart), those in which it featured substantively within a broader argument (green in the bar chart), and those in which it appeared only incidentally (yellow in the bar chart). The analysis focuses on the first two categories, as illustrated in the data selection flow diagram (Figure 2).

The resulting corpus ($N = 281$) spans a wide range of scientific fields, including medicine, biology, earth sciences, and space sciences (see Table 1). Across these domains, AI is

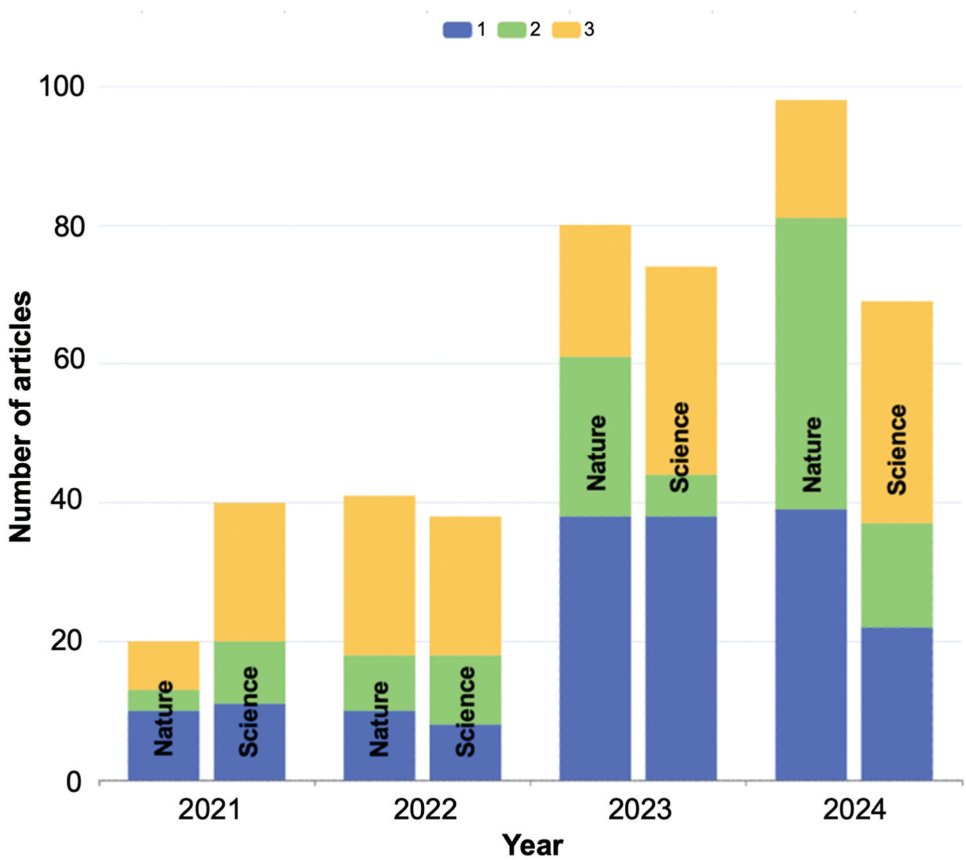

Figure 1. Frequency of commentaries mentioning AI in *Nature* and *science* prior to data cleaning.

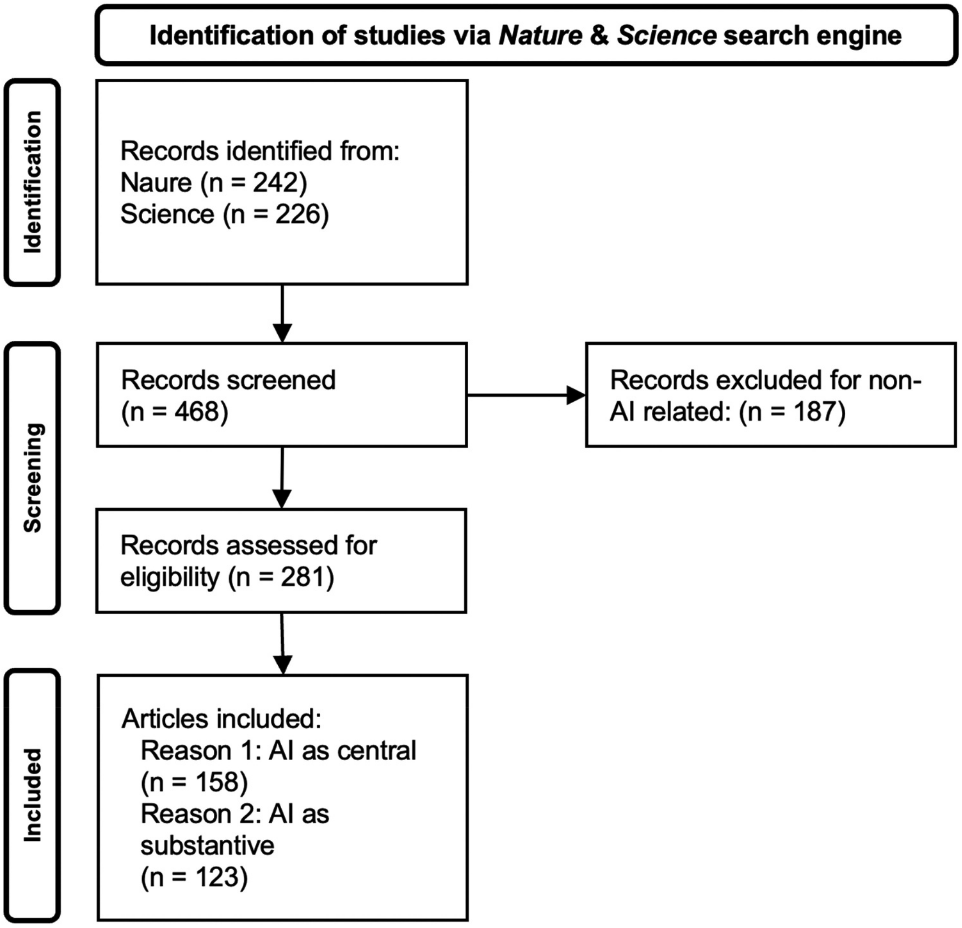

Figure 2. Flow diagram of data selection.

not treated as a discrete technical tool but as implicated in how scientific work is conducted, evaluated, organised, governed, and publicly legitimised. This is particularly evident in medical and life-science commentaries, where AI-related discussion is closely tied to data practices, infrastructural conditions, professional norms, and science – society relations.

The analysis was guided by the FRA – NOS, used as a sensitising orientation rather than a classificatory framework. Consistent with its Wittgensteinian foundations, FRA – NOS directed attention to epistemic, methodological, social, institutional, political, and value-laden dimensions of scientific practice without treating these as discrete categories. Engagement with the eleven FRA – NOS categories also formed part of the reflexive analytic process. Prior to and alongside the present analysis, the same dataset was examined quantitatively across FRA – NOS dimensions (Chan and Erduran 2025). This earlier engagement did not function as a coding template, but as a sensitising resource that oriented attention to how these dimensions are invoked, combined, and blurred within the corpus. In this sense, reflexivity was enacted through an ongoing dialogue between prior category-driven readings and the present interpretive analysis.

Table 1. Categories and examples of eligible articles.

Category	Example Title	2021	2022	2023	2024
Biology	How AI could lead to a better understanding of the brain	6 (0.16)	5 (0.13)	5 (0.05)	5 (0.04)
Chemistry	Digitalisation paving the ways for sustainable chemistry: switching on more green lights	0 (0)	0 (0)	1 (0.01)	2 (0.02)
Physics	Bioinspired nanofluidic iontronics	2 (0.05)	1 (0.03)	0 (0)	1 (0.01)
Climate, Energy, & Environmental science	Generative AI's environmental costs are soaring – and mostly secret	0 (0)	2 (0.05)	6 (0.05)	12 (0.1)
Computer Science	Breaking into the black box of artificial intelligence	2 (0.05)	1 (0.03)	3 (0.03)	6 (0.05)
Science Education	AI is transforming how science is done. Science education must reflect this change.	1 (0.03)	2 (0.05)	7 (0.06)	4 (0.03)
Engineering	Bioinspired robots walk, swim, slither and fly	1 (0.03)	2 (0.05)	3 (0.03)	1 (0.01)
Maths	Why mathematics is set to be revolutionised by AI	0 (0)	0 (0)	1 (0.01)	1 (0.01)
Medicine	Randomised trials of cancer drugs are for yesterday	**5 (0.14)**	**3 (0.08)**	**8 (0.07)**	**16 (0.13)**
General Scientific Practices	ChatGPT: five priorities for research	**1 (0.03)**	**4 (0.11)**	**21 (0.20)**	**29 (0.26)**
Philosophy	An exploration of real, virtual, and possible minds	6 (0.16)	2 (0.05)	17 (0.17)	10 (0.09)
Psychology	Time to regulate AI that interprets human emotions	1 (0.03)	1 (0.03)	0 (0)	0 (0)
Public health	Neglecting sex and gender in research is a public-health risk	0 (0)	1 (0.03)	0 (0)	2 (0.02)
Politics	War in an automated, data-driven world	4 (0.11)	3 (0.08)	10 (0.09)	11 (0.09)
Society & Culture	Art in the age of artificial intelligence	**3 (0.08)**	**8 (0.21)**	**19 (0.18)**	**13 (0.12)**
Total		**32**	**35**	**101**	**113**

Note: Numbers in parentheses indicate the proportion of total articles for that year.

Initial engagement involved repeated reading of the corpus to establish familiarity and identify points of analytic interest. Segments were then inductively coded, with FRA – NOS informing interpretation without functioning as a predefined coding scheme. Codes captured how AI was articulated within scientific discourse (see Table 2). For example, discussions of the limits of AI reasoning and the need for oversight were coded as *human judgement and epistemic limits*; concerns about closed models and reproducibility as *opacity and dependency*; references to energy demands and resource concentration as *infrastructural inequality*; and descriptions of shifting research practices as *reconfiguration of scientific labour*.

Across the corpus, a consistent pattern is that AI is rarely articulated within a single FRA – NOS dimension. Individual commentaries frequently link epistemic claims with methodological judgement, professional responsibility, institutional organisation, and social values within the same argumentative move. These observations establish the rationale for the analytic strategy adopted in the following section. Rather than organising findings according to predefined FRA aspects, the analysis identifies cross-cutting thematic articulations – recurring patterns through which AI is made intelligible across multiple dimensions of scientific practice simultaneously.

Table 2. Development of cross-cutting themes about AI-mediated NOS.

Cross-Cutting Aspect from RTA	Key Initial Codes	FRA – NOS categories	How the Theme Reconfigures Science	Illustrative Example
Epistemic authority and judgement	Human judgement and epistemic limits; AI unreliability; evaluation; interpretive oversight	Knowledge; Methods; Scientific Ethos; Social Certification	Authority shifts from being located in individual expertise to being distributed across human – AI systems, requiring ongoing judgement, validation, and institutional support.	'LLMs cannot exhibit in-depth scientific reasoning . . . ' (Zou 2024, 10)
Infrastructural dependency and material conditions	Opacity and dependency; compute access; energy demands; data inequality; platform reliance	Methods; Social Organisation; Political Power; Financial Systems; Social Values	Scientific practice becomes dependent on material infrastructures (compute, data, energy), making participation uneven and linking epistemic work to economic and political conditions.	'The energy required . . . could limit who can create and use them' (Bourzac 2024, para. 4)
Scientific labour and professional roles	Reconfiguration of labour; AI-assisted writing; automation; authorship; reskilling	Practices; Professional Activities; Social Organisation; Scientific Ethos	Scientific work shifts from production to oversight, with new hybrid roles emerging and responsibility redistributed across human – AI collaborations.	'AI outputs as a starting point rather than as the final product' (Rajaratnam 2024, para. 9);
Collective governance and coordination	Regulation; audits; standards; interdisciplinary collaboration; institutional oversight	Political Power; Social Organisation; Professional Activities; Social Certification	Governance becomes procedural and collective, involving standards, audits, and coordination across institutions rather than individual self-regulation.	'Developers . . . need to specify which AI capabilities are most likely to lead to . . . pandemic-scale harm' (Pannu et al. 2024, 810).
Legitimacy and public trust	Transparency; reproducibility; trust; peer review strain; misinformation risks	Scientific Ethos; Social Certification; Social Values; Aims and Values	Scientific legitimacy becomes contingent on transparency, accountability, and alignment with societal values, rather than technical output alone.	'[S]cientists can produce insights that both advance basic understanding and address societal needs' (Wang 2024, 794)

Cross-cutting thematic articulation

Building on the corpus overview and analytic orientation outlined above, this section presents the results of a reflexive thematic analysis of scientists' commentaries on AI. Themes are treated as analytic constructions generated through iterative and reflexive engagement with the corpus, rather than as summaries of predefined topics or mappings onto fixed conceptual categories. The aim is not to stabilise meanings associated with AI, but to articulate recurring patterns through which AI is made intelligible within contemporary scientific discourse.

Rather than organising findings around individual FRA – NOS categories, the analysis foregrounds themes that cut across epistemic, methodological, social, institutional, and value-laden dimensions of scientific practice simultaneously. This analytic move is grounded in the empirical character of the corpus itself. Across the commentaries, AI is rarely discussed as a concern confined to a single aspect of science. Instead, it is routinely articulated through entangled concerns involving epistemic authority and judgement, material infrastructure and dependency, professional labour and roles, collective governance and coordination, and legitimacy and public trust. FRA – NOS functions here as a conceptual backdrop that sensitises the analysis to these dimensions, while reflexive thematic analysis allows their overlap, fluidity, and reconfiguration to remain analytically visible rather than being forced into stable aspects of NOS.

AI as a reconfiguration of epistemic authority and judgement

Across the corpus, AI is discussed not simply as a new tool for scientific work, but as a development that unsettles established configurations of epistemic authority and redistributes judgement across epistemic practices, professional roles, and institutional arrangements. Scientists' narratives do not present AI as an objective epistemic agent or a neutral extension of human reasoning. Instead, they foreground ongoing negotiation over who or what has the standing to generate, evaluate, and validate knowledge claims. This pattern resonates with concerns raised by Cooper, Tang, and Rappa (2024) that generative AI may be taken up as an epistemic authority on the basis of fluency and confidence rather than epistemic warrant, although the commentaries analysed here largely resist such a displacement.

A recurring concern involves the apparent authority of AI-generated outputs and the risk that speed, scale, or rhetorical polish may be mistaken for reliability or evidential adequacy. Large language models are frequently described as producing persuasive outputs that can obscure uncertainty, weak grounding, or methodological limitations. This tension appears across contexts including peer review, medicine, and scientific communication, where authoritative presentation risks masking epistemic fragility. In these accounts, the evaluation of knowledge claims becomes entangled with computational performance, raising questions about how epistemic aims such as reliability, robustness, and justification are secured when judgement is partially delegated to AI systems.

At the same time, scientists' narratives strongly reassert the irreducibility of human judgement as a core epistemic practice. AI systems are consistently described as incapable of authorship, accountability, or responsibility for scientific claims. Competent scientific work is therefore framed as involving the capacity to interrogate AI outputs, assess provenance, recognise limits, and decide when outputs should not be trusted. Judgement is repositioned not as a source of bias to be eliminated, but as a professional responsibility through which knowledge claims are warranted and contextualised.

Importantly, this reconfiguration of epistemic authority is not framed as an individual challenge alone. Judgement is repeatedly linked to social and institutional mechanisms of certification, including peer review, disclosure norms, auditing practices, and standards of evaluation. Calls for transparency, explainability, and independent oversight reflect an understanding that epistemic authority is sustained through collective practices and institutional arrangements rather than residing in tools or outputs alone. Authority thus emerges as a distributed accomplishment coordinated across epistemic aims, professional responsibilities, and institutional infrastructures.

AI as infrastructure: materiality, dependency, and uneven capacity

Alongside questions of epistemic authority, the corpus consistently frames AI as an infrastructural and material condition of contemporary science. Rather than treating AI as a detachable tool that can be straightforwardly adopted or rejected, scientists' narratives emphasise dense assemblages of energy, data, hardware, labour, and institutional support through which AI-enabled science is made possible and through which participation is simultaneously enabled and constrained.

Across domains, AI is embedded in material infrastructures that include high-performance computing resources, cloud platforms, data centres, sensors, energy supply, and network connectivity. These infrastructures are not presented as neutral backdrops to scientific work, but as active determinants of what research can be pursued, at what scale, and by whom. Recurrent references to the cost of model training, the energy demands of computation, and the environmental footprint of AI signal that methodological choices are inseparable from material, ecological, and economic conditions. In this respect, the narratives resonate with Tang and Cooper's (2025) argument that epistemic authority depends on engagement with material reality rather than linguistic or symbolic fluency alone.

A salient pattern concerns growing dependencies on proprietary infrastructures, particularly those controlled by large technology companies. Closed models, opaque application programming interfaces, and rapidly evolving commercial systems are described as introducing vulnerabilities into scientific practice, including threats to reproducibility, long-term access, and institutional autonomy. In health care and policy-relevant research, such dependencies are framed as especially consequential, raising concerns about continuity, accountability, and institutional lock-in. From a material epistemic standpoint, these dependencies are not merely logistical but epistemically consequential, echoing Tang and Cooper's (2025) caution that AI systems lack direct referential grounding in the physical world.

These dependencies are unevenly distributed. Scientists repeatedly draw attention to global and regional asymmetries in access to compute, data, energy, and training. Commentaries focused on low- and middle-income contexts highlight how unreliable electricity supply, expensive cloud access, and limited local data infrastructures constrain the development and uptake of AI, even where scientific expertise and societal need are substantial. In these accounts, AI appears not merely as a technological frontier, but as a site where historical and structural inequalities in science are reproduced and intensified.

Crucially, infrastructural concerns cut across epistemic, social, and political dimensions of science without collapsing into any single one. Material conditions shape which methods are feasible, which collaborations are viable, and which research questions are prioritised. They also inform ethical debates about sustainability and extraction, as well as political discussions about sovereignty, regulation, and public investment. Infrastructure thus functions as a connector linking knowledge production to social organisation, economic systems, and governance arrangements.

AI and the reconfiguration of scientific labour and professional identity

Beyond epistemic authority and material infrastructure, the corpus consistently frames AI as reshaping the organisation of scientific labour and the meaning of professional activity.

Rather than depicting AI as merely increasing efficiency within existing roles, scientists' narratives emphasise shifts in how work is distributed, what kinds of contributions are valued, and how professional responsibility is enacted and recognised within scientific communities. These changes are uneven, unfolding across institutional, disciplinary, and geographical contexts.

A recurrent pattern concerns the redistribution of routine and high-volume work. Commentaries frequently describe AI as taking on activities such as drafting text, formatting documents, generating code, screening data, or summarising literature. These shifts are not framed as simple substitutions of human effort, but as reconfigurations that alter what counts as substantive scientific work. Productivity gains are accompanied by reflexive questioning of whether long-standing practices, such as grant writing, peer review, or manuscript preparation, retain their purpose when substantial portions can be automated.

At the same time, the delegation of routine tasks does not eliminate labour but reshapes professional expectations. Scientists are increasingly portrayed as responsible for overseeing, curating, verifying, and revising AI-assisted outputs. Professional competence is redefined less in terms of direct production and more in terms of exercising judgement about when, how, and whether AI-generated material should be used. This shift foregrounds forms of labour that are often invisible or undervalued, including error detection, bias assessment, contextual interpretation, and accountability for downstream consequences.

Another prominent pattern is the expansion and diversification of professional roles. AI-inflected scientific work is described as extending beyond traditional research activities to include guideline development, ethics committees, red-teaming exercises, policy advisory groups, and public engagement. These activities are framed as increasingly central forms of professional contribution in contexts where AI introduces new risks, uncertainties, and societal implications. Professional identity is thus broadened to encompass stewardship, coordination, and public-facing responsibility, often across institutional and national boundaries.

The corpus also highlights how AI reshapes collaboration and interdisciplinarity. Scientific work is increasingly distributed across teams that bring together domain scientists, computer scientists, clinicians, social scientists, and legal or policy specialists. Rather than positioning AI expertise as a service function, scientists emphasise reciprocal collaboration, shared problem framing, and mutual learning. This reorganisation challenges established professional hierarchies while introducing new coordination demands shaped by differences in resources, institutional location, and access to AI infrastructures.

These shifts are accompanied by concerns about workload, precarity, and professional inequality. While some narratives emphasise time savings and relief from administrative burden, others point to intensified expectations, accelerated cycles of production, and uneven access to AI-related skills. Early-career researchers, reviewers, and educators are frequently positioned at the front lines of these changes, navigating evolving norms without stable guidance or institutional consensus. In this sense, AI is portrayed as redistributing pressure across roles, career stages, and scientific communities rather than reducing labour overall.

AI, collective governance, and the coordination of scientific practice

Across the corpus, AI is framed not only as a technical or professional challenge, but as a catalyst for new forms of collective governance and coordination within science. Scientists' commentaries consistently suggest that established norms, informal trust mechanisms, and discipline-bound self-regulation are increasingly insufficient for managing the scale, opacity, and societal consequences of AI-enabled research. Governance emerges as a shared concern oriented less toward controlling individual behaviour and more toward coordinating scientific activity across institutions, sectors, and national boundaries.

A central pattern concerns the proliferation of standards, guidelines, and formalised procedures. Commentaries frequently refer to reporting standards, disclosure requirements, auditing frameworks, and evaluation protocols intended to render AI use more visible and accountable across diverse research settings. These mechanisms are not portrayed as bureaucratic add-ons, but as necessary responses to the speed and complexity of AI systems, which strain traditional forms of peer oversight. Governance is therefore framed as procedural rather than discretionary, with legitimacy increasingly tied to adherence to shared processes of evaluation and reporting.

Closely related is an emphasis on independent oversight and third-party evaluation. Rather than relying solely on individual researchers, journals, or institutions, scientists call for audits conducted by independent bodies, consortia, or publicly accountable organisations. Proposals for specialised AI safety institutes, international panels, and cross-sector review bodies recur across the corpus, signalling a shift from trust-based governance toward structured systems of verification and monitoring. These arrangements are framed not as replacements for scientific judgement, but as supports that enable judgement to be exercised collectively and transparently.

The corpus also portrays governance as inherently multi-level. AI governance is described as unfolding within laboratories, journals, and professional communities; across national policy contexts; and through international coordination. Fragmented or unilateral approaches are repeatedly described as inadequate, particularly given the transnational circulation of AI systems, data, and research outputs. Declarations, summits, and international agreements are therefore framed as attempts to align expectations and responsibilities across otherwise disconnected actors and jurisdictions.

Governance is not presented as value-neutral or purely technical. Decisions about standards, thresholds, and acceptable uses of AI are described as embedding normative judgements about risk, harm, responsibility, and public interest. Debates about regulatory boundaries, such as which applications warrant heightened scrutiny, are framed as matters of collective deliberation rather than technical optimisation.

AI, scientific legitimacy, and public trust

Beyond governance and coordination, scientists' discussions of AI consistently turn to concerns about the legitimacy of science and its relationship with public trust. Across the corpus, AI is framed as intensifying long-standing anxieties about whether scientific practices remain aligned with societal values, and whether scientific authority can be sustained under conditions of automation, opacity, and rapid technological change.

A prominent pattern is the recognition that scientific legitimacy can no longer be assumed. Commentaries suggest that the production of technically sophisticated outputs is insufficient to secure trust when AI systems are involved. Instead, legitimacy is portrayed as contingent on visible alignment with broader social values such as fairness, transparency, responsibility, and care. AI thus renders the value-laden character of scientific work more explicit.

Closely related is an emphasis on trust as a relational and institutional achievement rather than a property of AI systems themselves. Scientists repeatedly stress that trust is placed in people, institutions, and processes, not in algorithms. AI-generated outputs may appear authoritative, but without identifiable human responsibility and institutional accountability, they risk undermining confidence rather than strengthening it.

The corpus also highlights how AI foregrounds value conflicts. Tensions between efficiency and care, innovation and restraint, openness and protection, or global benefit and local harm recur across commentaries. AI is not depicted as resolving these tensions, but as making them unavoidable and more visible.

Another recurring concern is the fragility of trust in the context of misinformation, deepfakes, and automation bias. Scientists express anxiety that AI-enabled fabrication or persuasive outputs could erode confidence not only in particular findings, but in scientific communication more broadly. The risk is framed less as deliberate deception than as confusion about reliability, accountability, and evaluative responsibility.

Finally, legitimacy is portrayed as collectively negotiated rather than unilaterally declared. Commentaries emphasise dialogue with publics, inclusion of affected communities, and sensitivity to cultural and historical contexts as conditions for legitimate science in an AI-inflected world.

Discussion

The analysis of scientists' narratives published in high profile outlets *Nature* and *Science* enabled us to examines how AI is articulated within contemporary scientific discourse and helped us consider the implications of these articulations for the NOS. Using the FRA and Wittgenstenian lenses, rather than treating AI as a discrete 'impact factor' acting on an otherwise stable scientific enterprise, the analysis shows that AI is woven into scientific practice in ways that cut across epistemic aims, material infrastructures, professional roles, institutional arrangements, governance practices, and public legitimacy. Across the corpus, AI is rarely discussed as a concern confined to a single FRA – NOS aspect. Instead, it is repeatedly framed through patterns that simultaneously invoke questions of knowledge, authority, infrastructure, labour, coordination, and trust.

The paper forms part of a broader research programme investigating how AI is reshaping scientific practice and challenging conventional NOS frameworks. Within this programme, Chan and Erduran (2025) analyse the increasing entanglement of NOS dimensions in AI-related discourse, while Chan and Erduran (2026) offer a philosophically grounded account of epistemic judgement in situated encounters with AI. The present study contributes a complementary perspective by tracing how such entanglements recur systematically across a large corpus of scientists' commentaries. Its distinctive contribution lies in showing how AI is repeatedly made intelligible in influential scientific forums and how this reconfigures relationships among epistemic, institutional, and value-laden dimensions of science at scale.

A further contribution of the study lies in its methodological stance. Much FRA – NOS research in science education has relied on analytic traditions that privilege early category specification, topic-oriented coding, and demonstrations of reliability, often operationalised through intercoder agreement statistics (e.g. Chan et al. 2023). As Cheung and Tai (2023) argue, such practices are frequently adopted without explicit epistemological justification and risk reifying analytic categories as stable entities rather than treating them as interpretive tools. Even when the FRA is invoked to resist essentialist definitions of science, it is often operationalised in ways that re-stabilise boundaries between epistemic, social, and institutional aspects, effectively turning FRA into a classificatory checklist – an approach that sits uneasily with calls to treat FRA – NOS categories as dynamically interwoven (Chan 2025).

The present study deliberately departs from this orientation. Drawing on reflexive thematic analysis (Braun and Clarke 2021), themes are treated not as entities discovered in the data nor as fixed NOS components, but as analytic constructions generated through sustained, reflexive engagement with the corpus. FRA – NOS is used as a set of sensitising concepts that orient attention to epistemic, social, institutional, and value-laden dimensions, while allowing themes to develop across those dimensions rather than within them. This approach empirically enacts the fluid boundaries across FRA-NOS categories identified by Chan (2025) and directly responds to Cheung and Tai's (2023) critique by foregrounding analytic judgement, reflexivity, and theoretical coherence over coding consensus.

Empirically, the cross-cutting themes identified here, including AI as a reconfiguration of epistemic authority, a material and infrastructural dependency, a reorganisation of scientific labour, a catalyst for collective governance, and a pressure point for legitimacy and public trust, demonstrate that AI intensifies long-standing tensions within science rather than introducing entirely novel ones. What AI does is render these tensions more visible, more tightly coupled, and more consequential. Discussions of AI-generated knowledge routinely intertwine concerns about epistemic reliability with those of infrastructure, corporate control, professional accountability, and public trust, challenging attempts to treat NOS dimensions as analytically separable. Taken together, the findings support a relational understanding of science as a sociotechnical practice in which FRA – NOS boundaries are continually reworked through practice.

Implications

The study has numerous specific implications for NOS teaching and learning and more broadly for other aspects of science education. The themes articulated in Table 2 can be further elaborated to highlight some example scenarios that are implied for NOS teaching and learning when AI mediation of science is at play. They also highlight a shift away from assumptions that have long underpinned school science. Curricular models grounded in data scarcity and linear inquiry (Xie et al. 2025) are increasingly misaligned with scientific practices characterised by data abundance, large-scale infrastructures, and AI-supported pattern discovery. This shift extends data literacy beyond representation and interpretation to include critical engagement with data provenance, bias, uncertainty, and the limits of algorithmic inference. In the rest of this section, we consider these implications in more detail.

Reframing NOS teaching and learning

From a NOS perspective, the findings reaffirm the value of the FRA in capturing science as a constellation of epistemic, social, institutional, and value-laden practices. At the same time, they expose the limitations of instructional approaches that treat these dimensions as separable learning outcomes. Scientists' discussions of AI consistently cut across epistemic judgement, methodological practice, professional responsibility, infrastructure, governance, and public trust. Teaching NOS in the age of AI therefore calls for pedagogies that foreground relationships, tensions, and trade-offs across dimensions, rather than presenting science as a set of stable components to be mastered independently.

FRA provides a comprehensive framework to reframe science education in light of AI-mediated science. Although from a disciplinary perspective the FRA categories are inter-related and rarely occur in isolation as discussed previously, for educational purposes identifying some examples can be beneficial for educational purposes to guide the content of NOS teaching and learning. As Table 3 illustrates, there are implications of the discussion in relation to all aspects of NOS teaching and learning often with well-researched pedagogical approaches to teaching and learning of science, such as the use of peer assessment (Anker-Hansen and Andrée 2019) and debates (Dillon and Watts 2023).

In considering the role of AI in NOS, science curricula can incorporate a renewed focus on efficiency and speed as key drivers of scientific investigations using AI tools. Science curricula can also promote students' evaluation of scientific practices and critical discussion of the role of AI-generated data analysis in explaining and predicting phenomena. In contrast to well-articulated myth of the scientific method as a linear unproblematic process (Woodcock 2014) students will now learn about the diversity of scientific methods and the importance of data privacy issues raised by AI generated data sets. The dynamic nature of scientific knowledge is brought to the foreground in teaching and learning as well as data literacy (Qiao et al. 2024). Students question the probabilistic nature of scientific knowledge, a theme that has been raised for some time (e.g. Tobin 1982) but that has been relatively under-investigated in science education research.

The changing dynamics of AI-mediated NOS will have not only epistemic and cognitive but also social aspects of science teaching and learning. Students will now be aware that there is now a broad range of careers related to science, data science and computer science given the AI turn in science. Furthermore, given their increasing use of GenAI tools like ChatGPT, they will reocgnise AI as a collaborator in pursuing scientific problems and use GenAI in science projects. Teaching of AI ethics also becomes a regular feature of science lessons focusing on different aspects of AI use in various stages of the scientific process including data analysis and communication of scientific knowledge (Crawford 2021). Students can be encouraged to evaluate each other's work generated when GenAI tools have been used. Peer discussion and assessment (Zhai and Nehm 2023) include reference to the role of AI in ethical conduct of science.

Respect for social justice is contextualised in relation to the use of AI in science lessons. Students recognise the inherent social biases presented by AI datasets. Cross-subject collaboration is encouraged in science teaching and learning (MacKinnon, Hine, and Barnard 2013) in novel ways. Teachers of science collaborate with teachers of other subjects in lesson planning and teaching to expose students to a range of stakeholders and uses of AI. Science lessons infuse case studies (e.g. Irwin 2000) of how AI-mediated

Table 3. Aspects of AI-mediated science and educational applications.

Aspect of NOS	How AI mediates science	Example in AI-mediated science	Example educational applications
1. Aims and Values	AI shifts scientific aims from purely hypothesis-driven inquiry to data-driven, predictive, and efficiency-oriented goals. The focus moves from explanatory understanding to practical problem-solving.	AI-driven diagnostic tools prioritise prediction accuracy and speed in disease detection, such as early cancer diagnosis.	Science curricula incorporate a renewed focus on efficiency and speed as key drivers of scientific investigations using AI tools
2. Practices	AI automates routine scientific practices, including data analysis. Human roles shift toward oversight and interpretation of AI outputs.	AI models help explain and predict phenomena, and contribute to hypothesis generation and testing	Science curricula promote students' evaluation of scientific practices and critical discussion of the role of AI-generated data analysis in explaining and predicting phenomena
3. Methods	AI introduces new methods such as machine learning, iterative model training, and federated learning. These methods emphasise adaptation and self-improvement of AI models.	Federated learning enables training of AI models across multiple datasets without transferring raw data, enhancing privacy and data security. AI models use iterative feedback loops to refine experimental protocols and adapt methods dynamically, unlike traditional static research methodologies.	Students learn about the diversity of scientific methods including AI-generated hypotheses, and the importance of data privacy issues raised by AI generated data sets.
4. Knowledge	Knowledge in AI-driven science becomes dynamic, probabilistic, and evolving, moving away from fixed theoretical explanations. The concept of certainty becomes more fluid.	AI climate models continuously update predictions based on new incoming data, leading to 'adaptive knowledge' rather than static truths. AI models operate as 'black boxes' where the internal logic is opaque, raising epistemological questions about the transparency and reliability of AI-generated knowledge.	The dynamic nature of scientific knowledge is brought to the foreground in teaching and learning. Students question the probabilistic nature of scientific knowledge.
5. Professional Activities	Professional activities are reconfigured as scientists collaborate with computer scientists and data engineers. New roles emerge for 'AI curators' and 'AI model auditors'.	Scientists increasingly engage in 'human-AI collaboration' where AI handles technical analysis while researchers focus on oversight and interpretation. ChatGPT and similar tools assist in drafting research grant proposals, reducing human involvement in early manuscript preparation.	Students recognise that there is now a broad range of careers related to science, data science and computer science. Classroom activities expose students to AI as a collaborator in pursuing scientific problems and use GenAI in science projects.

(*Continued*)

Table 3. (Continued).

Aspect of NOS	How AI mediates science	Example in AI-mediated science	Example educational applications
6. Scientific Ethos	Scientific norms of scepticism, transparency, and integrity are redefined. AI-driven processes introduce concerns about authorship, accountability, and the opacity of AI-generated outputs.	Journals now require researchers to disclose their use of AI tools, like ChatGPT, in manuscript preparation, reflecting new expectations for transparency and integrity. The 'black-box problem' raises ethical questions about how scientists should trust and validate AI-generated insights when the reasoning behind them is not clear.	Teaching of AI ethics becomes a regular feature of science lessons focusing on different aspects of AI use in various stages of the scientific process including data harvesting, data analysis and communication of scientific knowledge.
7. Social Certification and Dissemination	The peer review process is increasingly mediated by AI. AI tools pre-screen submissions for ethical compliance, plagiarism, and technical flaws, shifting the burden from human reviewers.	AI review systems detect plagiarism and formatting issues before human reviewers assess the content, changing the review process.	Students are encouraged to evaluate each others' work generated when GenAI tools have been used. Peer discussion and assessment include reference to the role of AI in ethical conduct of science.
8. Social Values	AI in science reflects broader social values like efficiency, equity, and public health. However, it also raises concerns about fairness, bias, and inclusion in dataset representation.	Predictive AI models used in public health prioritise efficiency in forecasting disease outbreaks but may exclude underrepresented groups.	Respect for social justice is contextualised in relation to the use of AI in science lessons. Students recognise the inherent social biases presented by AI datasets.
9. Social Organisations and Interactions	AI reshapes research collaborations, encouraging interdisciplinary cooperation between scientists, computer engineers, and policy makers.	Universities and research consortia now form interdisciplinary research teams to address AI's technical, ethical, and societal implications, reflecting a broader shift in how science is organised.	Cross-subject collaboration is encouraged in science teaching and learning. Teachers of science collaborate with teachers of other subjects in lesson planning and teaching to expose students to a range of stakeholders involved in AI-mediated science.
10. Political Power Structures	Governments and corporations influence how AI-driven science is governed. This power dynamic shapes the types of research that are prioritised and which AI models are developed.	Governments like the EU enforce strict AI governance rules under the GDPR, affecting cross-border data use and research compliance. Large technology firms such as Google, Microsoft, and Amazon influence research agendas, often prioritising profitable AI-driven models.	Science lessons infuse case studies of how AI-mediated science is influenced by governments and technology firms.
11. Financial Systems	The financial ecosystem of science shifts toward private-sector funding, where large corporations prioritise research with high commercial potential, affecting the trajectory of scientific inquiry.	Research agendas now prioritise the development of commercialisable AI models for healthcare, emphasising efficiency over fundamental inquiry.	Science lessons include debates about commercialisation of science through AI and how scientific inquiry is influenced by funding priorities.

science is influenced by governments and technology firms. Science lessons include debates about commercialisation of science through AI and how scientific inquiry is influenced by funding priorities.

Broader reframing of science education

The cross-domain reconfigurations of scientific practice identified in this study have important implications for science education more broadly. If AI is experienced by scientists not as a detachable tool but as a force that reshapes epistemic judgement, material infrastructure, professional labour, governance, and public legitimacy in entangled ways, then educational responses cannot treat the 'AI turn' as an add-on to existing curricula. Rather than introducing isolated technical skills, stand-alone ethics modules, or surface-level references to AI, science education must reconsider how the nature of science itself is conceptualised, represented, and taught.

At the level of epistemic and methodological practice, the corpus highlights a shift away from assumptions that have long underpinned school science. Curricular models grounded in data scarcity and linear inquiry (Quai et al. 2024) are increasingly misaligned with scientific practices characterised by data abundance, large-scale infrastructures, and AI-supported pattern discovery. This shift extends data literacy beyond representation and interpretation to include critical engagement with data provenance, bias, uncertainty, and the limits of algorithmic inference (Schultheis and Kjelvik 2020). Rather than displacing theory, AI repositions theory, data, and computation within more fluid epistemic relationships, challenging the continued dominance of the linear 'scientific method' as a curricular organising principle (Ortiz-Revilla, Adúriz-Bravo, and Greca 2020).

The findings also foreground the centrality of ethical, social, and institutional considerations in scientific reasoning. As AI becomes embedded in research infrastructures, issues of fairness, representativeness, sustainability, and access arise directly from the conditions under which knowledge is produced. Although AI is sometimes framed as democratising science, the corpus documents persistent concentrations of power and uneven access to computational resources (Borenstein and Howard 2021). Meanwhile, AI systems can perpetuate or amplify biases present in training data. For example, an AI used in medical research may produce skewed results if it has been trained on datasets that underrepresent certain populations (DeCamp and Lindvall 2023). Similarly, an AI model trained on historical climate data might overlook key variables affected by human intervention or geopolitical factors (Shumailov et al. 2024). For science education, this positions equity, access, and authority as core features of scientific practice rather than as external ethical concerns.

Changes in scientific labour further reinforce the need for educational reorientation. Scientists describe AI not as eliminating work but as redistributing responsibility toward oversight, interpretation, coordination, and accountability. Emerging roles such as data stewards, model auditors, and interdisciplinary coordinators highlight the growing importance of collaborative judgement and institutional responsibility. Preparing students for participation in scientific practice therefore involves cultivating capacities for cross-disciplinary communication, ethical reasoning, and collective responsibility, rather than focusing narrowly on individual technical competence (Johnson et al. 2020).

More broadly, the findings position AI as a catalyst for reflexivity within science itself. Scientists are questioning how epistemic authority is established, how trust is sustained, and how legitimacy is earned in public contexts. These concerns have direct implications for scientific literacy and citizenship. Similar to arguments about the impact of the use of new tools such as augmented reality (e.g. Techakosit and Nilsook 2018), understanding science in an AI-mediated world requires attention not only to tools and methods, but to how knowledge circulates, how decisions are justified, and how science remains accountable to diverse publics.

Finally, these educational implications are inseparable from the methodological commitments of this study. By combining reflexive thematic analysis with a Wittgensteinian re-engagement of FRA – NOS, the analysis treats overlap, contestation, and partiality as constitutive features of contemporary science rather than analytic problems to be resolved. Responding to the AI turn in science education therefore requires not only curricular innovation, but methodological reflexivity in how the nature of science itself is studied and represented (Chan and Erduran 2026).

In summary in this paper, we argued that AI is transforming the nature of science (Erduran 2023). An 'AI turn' has occurred in the sciences and the mediation of the scientific enterprise through AI leads to new epistemological questions for science education. Our approach was based on a Wittgenstenian analysis of scientists' narratives in the top science outlets of *Nature* and *Science*, illustrating a range of issues including epistemic authority, scientific labour and public trust. Science curricula need to adapt to the emerging AI-driven scientific landscape so as to ensure that students' understanding of science is consistent with such emerging accounts of science.

Note

1. See the YouTube video *First reactions | Geoffrey Hinton, Nobel Prize in Physics 2024 | pers. comm*. on https://youtu.be/-icD_KmvnnM?si=kklWTzJN6rn7OqQt

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ORCID

Ho Yin Chan http://orcid.org/0000-0002-5455-3386
Sibel Erduran http://orcid.org/0000-0001-5226-0136

References

Akbayrak, M., and E. Kaya. 2020. "Fifth-Grade Students' Understanding of Social-Institutional Aspects of Science." *International Journal of Science Education* 42 (11): 1834–1861. https://doi.org/10.1080/09500693.2020.1790054.

Aksöz B., E. Kaya, and A. Çilekrenkli. 2025. "A Science Teacher's Autoethnographic Reflections on Teaching Nature of Science." *Science & Education* 34 (1): 247–280. https://doi.org/10.1007/s11191-023-00462-3.

Almasri, F. 2024. "Exploring the Impact of Artificial Intelligence in Teaching and Learning of Science: A of Empirical Research." *Research in Science Education* 54 (5): 977–997. https://doi.org/10.1007/s11165-024-10176-3.

Anker-Hansen, J., and M. Andrée. 2019. "Using and Rejecting Peer Feedback in the Science Classroom: A Study of Students' Negotiations on How to Use Peer Feedback When Designing Experiments." *Research in Science & Technological Education* 37 (3): 346–365. https://doi.org/10.1080/02635143.2018.1557628.

Baddour R. I., and S. BouJaoude. 2025. "Exploring the Nature of Science Conceptions of University Science Professors Using the Family Resemblance Framework." *Science & Education* 34 (5): 3015–3039. https://doi.org/10.1007/s11191-024-00535-x.

Bail, C. A. 2024. "Can Generative AI Improve Social Science?" *Proceedings of the National Academy of Sciences* 121 (21): 121. https://doi.org/10.1073/pnas.2314021121.

Barak, M. 2023. "Family Resemblance Approach in Science Education." *Science & Education* 32 (5): 1221–1225. https://doi.org/10.1007/s11191-023-00456-1.

Berber, S., M. Brückner, N. Maurer, and J. Huwer. 2025. "Artificial Intelligence in Chemistry Research: Implications for Teaching and Learning." *Journal of Chemical Education* 102 (4): 1445–1456. https://doi.org/10.1021/acs.jchemed.4c01033.

Bianchini, S., M. Müller, and P. Pelletier. 2022. "Artificial Intelligence in Science: An Emerging General Method of Invention." *Research Policy* 51 (10): 104604. https://doi.org/10.1016/j.respol.2022.104604.

Borenstein, J., and A. Howard. 2021. "Emerging Challenges in AI and the Need for AI Ethics Education." *AI and Ethics* 1 (1): 61–65. https://doi.org/10.1007/s43681-020-00002-7.

BouJaoude, S., Z. R. Dagher, and S. Refai. 2017. "The Portrayal of Nature of Science in Lebanese Ninth Grade Science Textbooks." In *Representations of Nature of Science in School Science Textbooks*, edited by C. V. McDonald and F. Abd-El-Khalick, 79–97. Abingdon, OXON: Routledge.

Bourzac, K. 2024. "Fixing AI's Energy Crisis." *Nature*. https://doi.org/10.1038/d41586-024-03408-z.

Boven L., R. Pinxten, S. Erduran, P. Van Petegem, and J. De Schrijver. 2026. "Shifting Away from Global Trends? Examining the Representation of the Nature of Science in the Flemish Curriculum in an International Policy Context." *International Journal of Science Education* 1–29. https://doi.org/10.1080/09500693.2026.2641833.

Braun, V., and V. Clarke. 2006. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology* 3 (2): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Braun, V., and V. Clarke. 2021. "One Size Fits All? What Counts as Quality Practice in (Reflexive) Thematic Analysis?" *Qualitative Research in Psychology* 18 (3): 328–352. https://doi.org/10.1080/14780887.2020.1769238.

Byrne, D. 2022. "A Worked Example of Braun and Clarke's Approach to Reflexive Thematic Analysis." *Quality and Quantity* 56 (3): 1391–1412. https://doi.org/10.1007/s11135-021-01182-y.

Cath, C., S. Wachter, B. Mittelstadt, M. Taddeo, and L. Floridi. 2017. "Artificial Intelligence and the 'Good Society': The US, EU, and UK Approach." *Science and Engineering Ethics* 24:505–528. https://doi.org/10.1007/s11948-017-9901-7.

Chan H., K. Cheung, and S. Erduran. 2023. "Science Communication in the Media and Human Mobility During the COVID-19 Pandemic: A Time Series and Content Analysis." *Public Health* 218:106–113. https://doi.org/10.1016/j.puhe.2023.03.001.

Chan, H. Y. 2025. "Rethinking the Dual Nature of Science." *Science and Education* 34 (6): 3959–3989. https://doi.org/10.1007/s11191-025-00634-3.

Chan, H. Y., K. K. C. Cheung, and S. Erduran. 2023. "Science Communication in the Media and Human Mobility During the COVID-19 Pandemic: A Time Series and Content Analysis." *Public Health* 218:106–113.

Chan, H. Y., and S. Erduran. 2025. "How Scientists' Narratives on AI Signal a New Era for Science Education." *Research in Science Education*. https://doi.org/10.1007/s11165-025-10307-4.

Chan, H. Y., and S. Erduran. 2026. "Science after Wittgenstein: Reading Encounters with the Affective Grammar of AI-Mediated Science and Educational Orientations." *Science & Education*.

Cheung K. Ka, H. Chan, and S. Erduran. 2023. "Communicating Science in the COVID-19 News in the UK During Omicron Waves: Exploring Representations of Nature of Science with Epistemic Network Analysis." *Humanities and Social Sciences Communications* 10 (1). https://doi.org/10.1057/s41599-023-01771-2.

Cheung K. Ka, A. Oancea and S. Erduran. "Students' Meaning-Making of Nature of Science: Interaction Between Visual, Verbal, and Written Modes of Representation." *Science Education* 109 (2): 480–505. https://doi.org/10.1002/sce.21916.

Cheung, K. K. C. 2020. "Exploring the Inclusion of Nature of Science in Biology Curriculum and High-Stakes Assessments in Hong Kong." *Science & Education* 29 (3): 491–512. https://doi.org/10.1007/s11191-020-00113-x.

Cheung, K. K. C., Y. Long, Q. Liu, and H.-Y. Chan. 2024. "Unpacking Epistemic Insights of Artificial Intelligence (AI) in Science Education: A Systematic Review." *Science & Education* 34 (2): 747–777. https://doi.org/10.1007/s11191-024-00511-5.

Cheung, K. K. C., and K. W. Tai. 2023. "The Use of Intercoder Reliability in Qualitative Interview Data Analysis in Science Education." *Research in Science & Technological Education* 41 (3): 1155–1175.

Chiu, T. K. 2023. "The Impact of Generative AI (GenAI) on Practices, Policies and Research Direction in Education: A Case of ChatGPT and Midjourney." *Interactive Learning Environments* 32 (10): 6187–6203. https://doi.org/10.1080/10494820.2023.2253861.

Cooper, G., K. S. Tang, and N. A. Rappa. 2024. "Generative Artificial Intelligence as Epistemic Authority?: Perspectives from Higher Education." In *Artificial Intelligence Applications in Higher Education*, edited by H. Crompton and D. Burke, 106–122. Routledge.

Crawford, K. 2021. *Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence*. London: Yale University Press.

DeCamp, M., and C. Lindvall. 2023. "Mitigating Bias in AI at the Point of Care." *Science* 381 (6654): 150–152. https://doi.org/10.1126/science.adh2713.

Dillon, J., and M. Watts. 2023. *Debates in Science Education*. London: Routledge.

Ding, L., T. Li, S. Jiang, and A. Gapud. 2023. "Students' Perceptions of Using ChatGPT in a Physics Class as a Virtual Tutor." *International Journal of Educational Technology in Higher Education* 20 (1): 63. https://doi.org/10.1186/s41239-023-00434-1.

Erduran, S. 2023. "AI Is Transforming How Science Is Done: Science Education Must Reflect This Change." *Science* 382 (6677). https://doi.org/10.1126/science.adm9788.

Erduran, S., and Z. R. Dagher. 2014. *Reconceptualizing the Nature of Science for Science Education*. Netherlands, Dordrecht: Springer. https://doi.org/10.1007/978-94-017-9057-4.

Erduran, S., and O. Levrini. 2024. "The Impact of Artificial Intelligence on Scientific Practices: An Emergent Area of Research for Science Education." *International Journal of Science Education* 46 (18): 1982–1989. https://doi.org/10.1080/09500693.2024.230660.

Fricke, K., and B. Reinisch. 2023. "Evaluation of Nature of Science Representations in Biology School Textbooks Based on a Differentiated Family Resemblance Approach." *Science & Education* 32 (5): 1583–1611.https://doi.org/10.1007/s11191-023-00444-5.

Haslam, S. A., P. Fong, C. Haslam, and T. Cruwys. 2024. "Connecting to Community: A Social Identity Approach to Neighborhood Mental Health." *Personality and Social Psychology Review* 28 (3): 251–275. https://doi.org/10.1177/10888683231216136.

Heeg, D. M., and L. Avraamidou. 2023. "The Use of Artificial Intelligence in School Science: A Systematic Literature Review. EMI." *Educational Media International* 60 (2): 125–150. https://doi.org/10.1080/09523987.2023.2264990.

Irwin, A. R. 2000. “Historical Case Studies: Teaching the Nature of Science in Context.” *Science Education* 84 (1): 5–26. https://doi.org/10.1002/(SICI)1098-237X(200001)84:1<5::AID-SCE2>3.0.CO;2-0.

Irzik, G., and R. Nola. 2014. “New Directions for Nature of Science Research.” In *International Handbook of Research in History*, Philosophy and Science Teaching, edited by M. Matthews, 999–1021. Netherlands, Dordrecht: Springer. https://doi.org/10.1007/978-94-007-7654-8_30.

Jia, F., D. Sun, and C. Looi. 2024. “Artificial Intelligence in Science Education (2013–2023): Research Trends in Ten Years.” *Journal of Science Education and Technology* 33 (1): 94–117. https://doi.org/10.1007/s10956-023-10077-6.

Johnson, C. C., M. J. Mohr-Schroeder, T. J. Moore, and L. D. English, eds. 2020. *Handbook of Research on STEM Education*. New York: Routledge.

Kaya, E., S. Erduran, and B. Okan. 2025. “Nature of Science and Domain-Specificity: Investigating the Coverage of Nature of Science in Physics, Chemistry and Biology Curricula Across Grade Levels.” *International Journal of Science Education* 47 (5): 697–727. https://doi.org/10.1080/09500693.2024.2348822

Kuhn, T. S. 1962. “The Nature and Necessity of Scientific Revolutions.” In *Knowledge: Critical Concepts*, edited by N. Stehr and R. Grundmann, 92–110. Vol. 5. Chicago: University of Chicago Press.

Lee, G., and X. Zhai. “Using ChatGPT for Science Learning: A Study on Pre-service Teachers’ Lesson Planning.” *IEEE Transactions on Learning Technologies* 17:1643–1660. https://doi.org/10.1109/TLT.2024.3401457.

Lo, C. K. 2023. “What Is the Impact of ChatGPT on Education? A Rapid Review of the Literature.” *Education Sciences* 13 (4): 410. https://doi.org/10.3390/educsci13040410.

Löhr, G. 2023. “Conceptual Disruption and 21st Century Technologies: A Framework.” *Technology in Society* 74:102327. https://doi.org/10.1016/j.techsoc.2023.102327.

MacKinnon, P. J., D. Hine, and R. T. Barnard. 2013. “Interdisciplinary Science Research and Education.” *Higher Education Research & Development* 32 (3): 407–419. https://doi.org/10.1080/07294360.2012.686482.

Messeri, L., and M. J. Crockett. 2024. “Artificial Intelligence and Illusions of Understanding in Scientific Research.” *Nature* 627 (8002): 49–58. https://doi.org/10.1038/s41586-024-07146-0.

Nature. 2022. “Method of the Year 2021: Protein Structure Prediction.” *Nature Methods* 19 (1): 1–1. https://doi.org/10.1038/s41592-021-01380-4.

Ortiz-Revilla, J., A. Adúriz-Bravo, and I. M. Greca. 2020. “A Framework for Epistemological Discussion on Integrated STEM Education.” *Science & Education* 29 (4): 857–880. https://doi.org/10.1007/s11191-020-00131-9.

Pannu, J., S. Gebauer, G. McKelvey Jr Jr, A. Cicero, and T. Inglesby. 2024. “AI Could Pose Pandemic-Scale Biosecurity Risks. Here’s How to Make It Safer.” *Nature* 635 (8040): 808–811. https://doi.org/10.1038/d41586-024-03815-2.

Pereira, B. B., and S. Ha. 2025. “Reconceptualized Family Resemblance Approach to the Nature of Science in Middle-School Science Textbooks from Brazil and South Korea Regarding Environmental Issues.” *Science & Education* 34 (4): 2283–2311. https://doi.org/10.1007/s11191-024-00514-2.

Qiao, C., Y. Chen, Q. Guo, and Y. Yu. 2024. “Understanding Science Data Literacy: A Conceptual Framework and Assessment Tool for College Students Majoring in STEM.” *International Journal of STEM Education* 11 (1): 25. https://doi.org/10.1186/s40594-024-00484-5.

Rajaratnam, V. 2024. “Why I’m Committed to Breaking the Bias in Large Language Models.” *Nature*. https://doi.org/10.1038/d41586-024-02839-y.

Schultheis, E. H., and M. K. Kjelvik. 2020. “Using Messy, Authentic Data to Promote Data Literacy & Reveal the Nature of Science.” *The American Biology Teacher* 82 (7): 439–446. https://doi.org/10.1525/abt.2020.82.7.439.

Shumailov, I., Z. Shumaylov, Y. Zhao, N. Papernot, R. Anderson, and Y. Gal. 2024. “AI Models Collapse When Trained on Recursively Generated Data.” *Nature* 631 (8022): 755–759. https://doi.org/10.1038/s41586-024-07566-y.

Takriti, R., H. Tairab, N. Alhosani, H. Elhoweris, L. Schofield, L. Rabbani, and I. AlAmirah. 2023. “Toward Understanding Science as a Whole.” *Science & Education* 32 (5): 1321–1361. https://doi.org/10.1007/s11191-022-00404-5.

Tang, K. S., and G. Cooper. 2025. “The Role of Materiality in an Era of Generative Artificial Intelligence.” *Science & Education* 34 (2): 731–746. https://doi.org/10.1007/s11191-024-00508-0.

Techakosit, S., and P. Nilsook. 2018. “The Development of STEM Literacy Using the Learning Process of Scientific Imagineering Through AR.” *International Journal of Engineering Technologies in Learning* 13 (1): 230–238. https://doi.org/10.3991/ijet.v13i01.7664.

Tobin, K. 1982. “Patterns of Reasoning: Probability.” *Research in Science Education* 12 (1): 42–49. https://doi.org/10.1007/BF02357012.

Van Noorden, R., and J. M. Perkel. 2023. “AI and Science: What 1,600 Researchers Think.” *Nature* 621 (7980): 672–675. https://doi.org/10.1038/d41586-023-02980-0.

Voss, S., I. Kent-Schneider, J. Kruse, and R. Daemicke. 2023. “Investigating the Development of Preservice Science Teachers’ Nature of Science Instructional Views Across Rings of the Family Resemblance Approach Wheel.” *Science & Education* 32 (5): 1363–1399. https://doi.org/10.1007/s11191-023-00418-7.

Wang, D. 2024. “How I’m Using AI Tools to Help Universities Maximize Research Impacts.” *Nature* 630 (8018): 794–794. https://doi.org/10.1038/d41586-024-02081-6.

Wei, B., Z. Jiang, and L. Gai. 2021. “Examining the Nature of Practical Work in School Science Textbooks: Coverage of the Diversity of Scientific Methods.” *Science & Education*. https://doi.org/10.1007/s11191-021-00294-z.

Wittgenstein, L. 1958. *Philosophical Investigations*. Oxford: Blackwell.

Woodcock, B. A. 2014. “The Scientific Method as Myth and Ideal.” *Science & Education* 23 (10): 2069–2093. https://doi.org/10.1007/s11191-014-9704-z.

Xie, J., L. Sun, and Y. F. Zhao. 2025. “On the Data Quality and Imbalance in Machine Learning-based Design and Manufacturing—A Systematic Review.” *Engineering* 45:105–131. https://doi.org/10.1016/j.eng.2024.04.024.

Zhai, X., and R. H. Nehm. 2023. “AI and Formative Assessment: The Train Has Left the Station.” *Journal of Research in Science Teaching* 60 (6): 1390–1398. https://doi.org/10.1002/tea.21885.

Zhai, X., M. Nyaaba, and W. Ma. 2024. “Can Generative AI and ChatGPT Outperform Humans on Cognitive-Demanding Problem-Solving Tasks in Science?” *Science & Education* 34 (2): 1–22.

Zou, J. 2024. “ChatGPT Is Transforming Peer Review — How Can We Use It Responsibly?” *Nature* 635 (8037): 10–10. https://doi.org/10.1038/d41586-024-03588-8.