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TEACHING THE NATURE OF STEM THROUGH ARGUMENT-DRIVEN INQUIRY (ADI): A CONCEPTUAL FRAMEWORK FOR INTERDISCIPLINARY CLASSROOMS

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Abstract

There is growing recognition that contemporary STEM education must move beyond disciplinary content to explicitly address the Nature of STEM (NoSTEM), the epistemic, methodological, social, and ethical dimensions of how STEM knowledge is produced and used in society. Integrated STEM initiatives often emphasize projects and products but pay insufficient attention to how learners understand the practices and values that underlie STEM disciplines and their interconnections. This conceptual paper argues that Argument-Driven Inquiry (ADI) offers a theoretically robust pedagogical approach for teaching the Nature of STEM in school settings. Drawing on recent NoSTEM and integrated STEM literature, the paper first clarifies the construct of Nature of STEM and distinguishes it from both traditional STEM and the Nature of Science (NOS). It then outlines why teaching NoSTEM is essential in today's context of socio-scientific challenges, AI-driven societies, and policy calls, such as India's NEP 2020, for inquiry-based, multidisciplinary learning. Next, the paper analyzes how ADI operationalizes core NoSTEM features by engaging students in investigation, modeling, evidence-based argumentation, critique, and reflection in interdisciplinary problem contexts. Illustrative classroom implications are presented to show how ADI can structure tasks that foreground epistemic, design, and socio-ethical aspects of STEM. The paper concludes with implications for curriculum design, teacher education, and future research on explicit NoSTEM learning outcomes in ADI-based STEM instruction.
Keywords: *Nature of STEM; integrated STEM; Argument-Driven Inquiry; argumentation; inquiry-based learning; NEP 2020.*

Introduction

International debates on STEM education have increasingly emphasized that preparing learners for the 21st century requires more than procedural mastery of science, mathematics, technology, or engineering content. Contemporary challenges such as climate change, pandemics, energy transitions, and AI governance demand that citizens understand how STEM knowledge is generated, justified, and applied across disciplinary boundaries. This has led to a shift from focusing only on "what" students know in STEM to considering their understanding of the Nature of STEM (NoSTEM), the aims, values, practices, and epistemologies that characterize and connect STEM disciplines.

At the same time, many integrated STEM initiatives have been criticized for centering on making products or completing projects without systematically addressing the underlying epistemic and socio-ethical dimensions of STEM work. Learners may build artifacts or solve tasks, yet still hold naïve views about how evidence, modeling, design constraints, and social values shape STEM decisions. In this context, Argument-Driven Inquiry (ADI), an inquiry and argumentation-based instructional model, offers a promising pedagogical pathway for making the Nature of STEM explicit in classroom practice.

This paper focuses on three core aims:

- Clarify the construct of Nature of STEM and distinguish it from traditional STEM and Nature of Science;
- Explain why teaching NoSTEM is necessary in today's educational and societal context, including in India under NEP 2020; and
- Theorize how ADI is compatible with, and well suited for, teaching the Nature of STEM.

Nature of STEM: From NOS to NoSTEM

The Nature of Science (NOS) tradition has long argued that science education should help learners understand characteristics of scientific inquiry such as empiricism, tentativeness, theory–data relations, and the role of creativity and social negotiation. Building on this, more recent scholarship has proposed the broader construct of Nature of STEM (NoSTEM), which extends attention beyond science to technology, engineering, and mathematics, and crucially to their integration.

Erduran's discussion "Nature of 'STEM'?" frames NoSTEM as encompassing the epistemic foundations of integrated STEM—how different STEM disciplines generate and validate knowledge, how design and modeling complement experiment, and how STEM practices are embedded in societal contexts. Rethinking NoSTEM, a more recent line of work, highlights that any attempt to conceptualize or assess NoSTEM must include epistemic, cognitive, social, and ethical dimensions rather than limiting attention to content and generic skills. These accounts converge on the view that understanding STEM literacy in a deep sense requires learners to grasp how STEM disciplines work, not only what they contain.

Distinguishing NoSTEM from traditional STEM and NOS

Traditional STEM instruction frequently treats science, mathematics, technology, and engineering as relatively separate subjects, with integration limited to thematic units or projects where disciplines are referenced side by side. A systematic review of integrated STEM instructional practices in secondary education found that many interventions emphasized cross-disciplinary projects but did not always foreground epistemic practices or disciplinary differences and connections. In contrast, NoSTEM emphasizes that each discipline has characteristic methods—for example, experimental testing in science, proof and abstraction in mathematics, design and optimization in engineering, and artifact development in technology, while also sharing commitments to evidence, coherence, and problem solving.

Compared with NOS, which traditionally focuses on science as a single discipline, NoSTEM attends to design logics, modeling practices, systems thinking, risk–benefit reasoning, and social purposes that are especially salient in engineering and technology. This means that teaching NoSTEM entails engaging learners with questions such as: How do engineers justify that a design is "good enough"? How do mathematicians and scientists decide whether a model is acceptable? How do technologists weigh usability, cost, and ethical considerations when deploying systems? These questions go beyond classical NOS lists and demand pedagogies that can surface such reasoning in classroom discourse.

Why Teaching the Nature of STEM Matters

Socio-scientific and techno-scientific challenges

Many of today's most urgent public issues—climate resilience, energy choices, genetic technologies, AI and automation, public health—are socio-scientific and techno-scientific in nature. Citizens must interpret data visualizations, understand the limitations of models, evaluate competing expert claims, and consider how different design options distribute risks and benefits across communities. Research on STEM literacy argues that without explicit attention to NoSTEM, learners may view STEM as neutral, purely technical problem solving, failing to recognize the role of uncertainty, values, and contested interpretations in STEM decision making.

Conceptual frameworks for integrated STEM have thus emphasized that curricula should not only integrate disciplinary content but also help students engage with the epistemic and ethical dimensions of STEM practices. For example, comprehensive integrated STEM frameworks highlight real-world problem contexts, engagement in authentic practices, and development of key competencies such as critical thinking, systems thinking, and collaboration as central design principles—each of which presupposes an understanding of how STEM knowledge is generated and judged.

Future of work and 21st-century competencies

Analyses of STEM education for the future workforce argue that students must develop adaptive expertise—the ability to flexibly apply knowledge to new situations, reason with data, and collaborate across disciplinary boundaries. Competency frameworks for STEM curriculum design identify key competencies such as problem solving, critical thinking, communication, and use of digital technologies, all grounded in meaningful engagement with STEM practices rather than rote technique. Without understanding NoSTEM, students' learning may remain fragile and context-bound, limiting their capacity to transfer knowledge and participate in innovation ecosystems.

Indian policy context: NEP 2020 and integrated STEM

In India, the National Education Policy (NEP) 2020 calls for a paradigm shift toward experiential, inquiry-driven, and multidisciplinary learning across school levels. The policy emphasizes critical thinking, problem solving, and scientific temper, encouraging pedagogies such as discussion-based, discovery-based, and project-based learning that go beyond textbook-driven instruction. Commentaries on NEP 2020 note that fostering scientific temper includes not just presenting canonical facts but engaging learners with how knowledge is constructed, questioned, and revised—core concerns of NoSTEM.

Emerging Indian literature on STEM and STEAM under NEP 2020 underscores the need for interdisciplinary projects, real-world problem contexts, and use of technology and engineering design in classrooms. However, these discussions also highlight challenges such as exam pressures, teacher preparedness, and the risk that projects remain superficial if epistemic aims are not clearly articulated. Integrating a Nature of STEM perspective into such reforms can provide a conceptual anchor for designing tasks that build both content and deep understanding of STEM practices.

Argument-Driven Inquiry (ADI): Overview and Evidence Base

Core structure of ADI

Argument-Driven Inquiry (ADI) is an instructional model that organizes laboratory and project work around cycles of investigation, argument construction, peer critique, and reflection. In a typical ADI sequence, students:

- explore a phenomenon and articulate initial ideas;
- design or carry out an investigation to generate data;
- construct written arguments that link claims to evidence via explicit reasoning;
- critique and compare arguments in small groups and whole-class discussion; and
- reflect on how and why their ideas have changed.

This structure positions argumentation and evidence evaluation at the center of learning rather than treating them as peripheral, end-of-lab reporting tasks. Through repeated cycles, students gradually appropriate discourse moves such as justifying claims, considering alternative explanations, and revising positions based on critique, which are central to scientific and engineering practice.

Empirical findings on ADI

Systematic reviews and empirical studies across various contexts have found that ADI improves students' scientific argumentation, critical thinking, and conceptual understanding compared to traditional, confirmatory laboratory instruction. Quasi-experimental work in secondary science has documented that students engaging in ADI produce arguments with higher structural quality, clearer claims, more relevant evidence, more sophisticated reasoning, than peers in conventional lab conditions.

Studies of ADI with scaffolding (e.g., ADI plus explicit supports for reasoning) report even larger gains in argumentation and critical thinking, indicating that pedagogical supports can enhance its impact. Researchers have also extended ADI into STEM and ADI–STEM hybrids. Research on ADI–STEM in interdisciplinary, technology-rich contexts shows that students using ADI-structured materials achieve significantly better scientific argumentation scores and gains in science literacy, including interpreting data, connecting STEM concepts to everyday issues, and understanding the role of evidence in STEM problem solving. Together, these findings support viewing ADI as a robust, research-backed pedagogy for cultivating epistemic practices that are central to NoSTEM.

Theoretical Compatibility between ADI and the Nature of STEM

Alignment with integrated STEM frameworks

Conceptual frameworks of integrated STEM commonly highlight features such as:

- real-world, complex problem contexts;
- integration of multiple STEM disciplines;
- centrality of STEM practices (e.g., modeling, inquiry, design, argumentation); and
- development of 21st-century competencies like collaboration and critical thinking.

ADI aligns with these features because it structures learning around open or semi-open problems, where students must collect or interpret data, construct and defend claims, and consider alternative explanations or designs. When tasks are framed around interdisciplinary issues—for example, designing energy-efficient housing or evaluating transport options—students in ADI settings must draw on science concepts, mathematical modeling, engineering design criteria, and technological constraints to build and critique arguments. This directly engages them with integrated STEM practices and brings NoSTEM dimensions into view.

Epistemic practices across STEM disciplines

NoSTEM scholarship emphasizes that STEM disciplines share overlapping but distinct epistemic practices such as experimentation, modeling, design, optimization, and proof. In ADI, students repeatedly engage in evaluating the quality and sufficiency of evidence, explicitly linking data to claims through reasoning, and weighing rival explanations or solutions.

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These activities approximate the core of scientific and engineering epistemic practice in age-appropriate ways, making visible that knowledge is not simply "found" but argued for, critiqued, and revised.

When ADI is combined with engineering or design-focused tasks, students must justify design decisions, for example, why a particular prototype, algorithm, or material choice is acceptable given empirical data, performance criteria, and constraints. This naturally incorporates engineering ways of knowing, where arguments often hinge on trade-offs, safety margins, cost–benefit analyses, and user needs as much as on purely scientific evidence. In mathematics-incorporating ADI tasks, students may be required to defend choices of models, approximations, or statistical approaches, thereby engaging with mathematical epistemic criteria such as logical coherence and fit to data. In this way, ADI can be seen as a general structure for orchestrating classroom engagement with diverse STEM epistemic practices.

Design, modeling, and systems thinking

Philosophical work on integrated STEM argues that design provides a unifying lens, linking problem framing, modeling, prototyping, testing, and optimization in STEM education. ADI can be extended from empirical investigations to design-based inquiries, where students develop and test solutions to real-world problems, then argue for the adequacy of their designs using criteria such as efficiency, feasibility, sustainability, and user impact. In such tasks, the ADI cycle supports students in articulating and scrutinizing the reasoning behind design choices, thereby illuminating how design and modeling are central to the Nature of STEM, not just peripheral applications.

Furthermore, when ADI prompts students to consider whole systems, for instance, an urban transport network or a school's energy usage, they must reason about interdependencies and trade-offs, key aspects of systems thinking highlighted as essential in integrated STEM frameworks. Structured argumentation about competing system-level interventions (e.g., different energy mixes, transport policies) helps learners appreciate that STEM problems rarely have single "right" answers; rather, they involve balancing multiple, often conflicting criteria within complex systems.

Socio-ethical and value dimensions

NoSTEM frameworks explicitly stress that STEM is embedded within social, ethical, and political contexts and that understanding STEM literacy entails recognizing how values, power, and equity shape STEM decisions. ADI is theoretically well positioned to engage students with these socio-ethical dimensions when used with socio-scientific and socio-technical issues such as climate policy, vaccination strategies, AI in education, or urban planning. In such contexts, ADI structures can require students to weigh empirical evidence (e.g., health data, emissions models) alongside ethical considerations (e.g., justice, privacy, intergenerational equity) and stakeholder perspectives.

By making reasoning explicit and open to critique, ADI fosters classroom discourse where students must justify not only what works but also what ought to be done, illuminating the value-laden nature of STEM decision making. Reflection phases in ADI can be used to prompt meta-discussion on questions such as "Whose evidence counted in our argument?" or "Which values did we prioritize in choosing this solution?", thereby deepening learners' understanding of the social and ethical dimensions of NoSTEM.

Discussion: Integrating NoSTEM, Integrated STEM, and ADI into Practice

NoSTEM as an extension of NOS and integrated STEM

Debates on NOS have long argued that science education should address how scientific knowledge is generated, justified, and revised, including aspects such as empiricism, theory-ladenness, tentativeness, creativity, and social embeddedness. Building on this tradition, recent work has broadened the focus from science alone to the Nature of STEM (NoSTEM), asking whether STEM has a coherent "nature" and what its epistemic underpinnings imply for education.

Erduran's editorial "Nature of STEM?" foregrounds that STEM has become a powerful policy slogan, yet its epistemological content is often underspecified; she argues that without attention to the aims, values, and practices of each discipline, integrated STEM risks either conflating or erasing important disciplinary differences. Park and colleagues' systematic analysis of curriculum standards shows that standards have begun to incorporate STEM and NOS, but tends to foreground science and shared science–engineering features while largely neglecting mathematics and technology as distinct epistemic enterprises. Their study demonstrates that simply naming STEM in standards does not guarantee that learners will encounter robust accounts of how STEM disciplines work or how they intersect.

Emerging NoSTEM frameworks, including models that explicitly incorporate epistemic, cognitive, social, and ethical dimensions, therefore extend both NOS and integrated STEM debates by insisting that STEM literacy requires understanding disciplinary and interdisciplinary ways of knowing, not only exposure to multi-subject projects. From this perspective, NoSTEM is not merely the sum of separate nature of science, nature of technology, nature of engineering, and nature of mathematics lists; rather, it is a synthetic construct that highlights how empirical inquiry, mathematical modelling, design and optimisation, artefact development, and socio-ethical deliberation jointly shape STEM activity.

Disciplinary characteristics through the Family Resemblance lens

The Family Resemblance Approach (FRA) conceptualises disciplines as "families" that share overlapping aims, values, methods, practices, and social-institutional arrangements, without being reducible to any single essence. When applied to STEM, FRA suggests that science, technology, engineering, and mathematics share family resemblances, for example, commitments to coherence, problem solving, and systematic reasoning, yet also exhibit distinctive epistemic profiles.

Science is characterized by aims such as explaining and predicting natural phenomena, building empirically constrained theories, and generating trustworthy knowledge about the natural world. Its central methods include observation, experimentation, data collection and analysis, and the iterative refinement of models and explanations in light of evidence. Epistemic values such as accuracy, objectivity, reliability, and critique, as well as social norms like honesty and openness to peer review, are widely emphasised in standards and history and philosophy of science literature.

Engineering, by contrast, is fundamentally solution-oriented and design-driven. Its aims involve devising, optimising, and justifying artefacts or systems that meet specified needs under constraints of cost, safety, feasibility, and regulation. Engineering methods centre on problem framing, design iteration, prototyping, testing, and trade-off analysis rather than explanation of natural phenomena. Values such as technical feasibility, reliability under constraint, efficiency, and responsiveness to users and contexts take on special salience, even as epistemic virtues like evidence and coherence remain important.

Technology, in history and philosophy of science-informed accounts, is concerned with the design, production, and use of artefacts and systems that are embedded in economic, political, and cultural relations. Park and colleagues note that contemporary science is inseparable from technology and engineering, with technoscientific fields (e.g., biotechnology, information technology) eroding boundaries between "pure" knowledge and practical invention, and with patents, markets, and industry becoming central to how STEM work is organised and valued. Technological activity therefore foregrounds values such as usability, marketability, standardisation, and intellectual property, which are less central in traditional images of science.

Mathematics has often been marginalised in STEM curriculum discourse, yet FRA-based analyses highlight that it brings distinct aims, methods, and standards of justification. Mathematics aims at describing and structuring patterns, relationships, and abstract entities through definitions, theorems, and proofs; its knowledge claims are validated via logical deduction and internal coherence rather than empirical testing. While mathematics contributes heavily to modelling in science and engineering, its non-empirical character, emphasis on proof, and aesthetic values such as elegance and simplicity differentiate its epistemic culture from that of empirical sciences.

Taken together, these FRA-informed descriptions support a nuanced account in which STEM disciplines share family resemblances but differ in their typical questions, forms of evidence, standards of acceptability, and relations to society and economy. Such nuance is essential if NoSTEM is to move beyond generic "STEM is integrated and 21st-century" rhetoric.

Interconnections and tensions among STEM disciplines

Although disciplinary differences matter, empirical and curriculum studies show that, in practice, STEM work is highly interdependent. Historical and policy documents emphasise that mathematics and technology are deeply entangled with science and engineering: technological innovations open new scientific possibilities, mathematical formalisms enable theoretical advance, and engineering design both depends on and reshapes scientific knowledge.

From an FRA standpoint, these interconnections can be seen along several dimensions:

- Aims and values: While science emphasises explanation and understanding, and engineering emphasises workable designs, both rely on evidence, coherence, and critical scrutiny; similarly, both must increasingly attend to social utility, sustainability, and justice as part of their value structure.
- Methods and practices: Practices such as modelling, argumentation, systems thinking, and optimisation appear across STEM, but in different configurations—experiments in science, simulations and prototypes in engineering, and formal proof or algorithmic reasoning in mathematics.

- Social-institutional dimensions: All STEM disciplines are shaped by funding structures, policy priorities, professional organisations, and global networks, though the roles of markets and patents tend to be more prominent in technology and engineering than in public-good images of science and mathematics.

Importantly, Park and colleagues show that current standards documents tend to highlight similarities, especially between science and engineering, more than differences, potentially leaving students with the impression that STEM is a homogeneous set of practices. Mathematics-specific aims and practices are rarely articulated, and technology is often folded into engineering or treated purely as application. NoSTEM-oriented teaching must therefore make both connections and distinctions explicit: learners should see, for example, how the same dataset can be interpreted scientifically (as evidence for a claim), mathematically (as a distribution or function), and technologically (as a design parameter in a device), and how these perspectives may sometimes pull in different directions.

Teachers' conceptions and classroom realities

Empirical work on teachers' conceptions of integrated STEM reveals both the opportunities and constraints for bringing NoSTEM into classrooms. Dare and colleagues, studying 19 K–12 science teachers after intensive STEM-focused professional development, found that participants overwhelmingly adopted an integrative, science-centred view of STEM that emphasised real-world problems, 21st-century skills, and student-centred pedagogy. At the same time, their conceptions of the roles of technology, engineering, and mathematics were uneven and sometimes contradictory.

Science was generally positioned as the central epistemic engine, the main source of disciplinary content and the starting point for curriculum design, while engineering was understood primarily as a design process or vehicle for problem solving, rather than as a knowledge domain with its own concepts and criteria. Technology was most often equated with digital tools or devices that support data collection, analysis, or presentation, and mathematics was framed largely as a set of skills or tools for graphing, calculating, or representing data, rather than as an epistemic system with distinctive ways of reasoning.

Dare and colleagues also report that teachers strongly endorsed the use of authentic, real-world problems, the development of "4C" 21st-century skills (critical thinking, creativity, collaboration, communication), and the promotion of STEM career awareness. However, these content-agnostic characteristics were usually discussed as general pedagogical goods rather than explicitly linked to disciplinary epistemologies or to systematic reflection on NoSTEM. Integrated STEM, in practice, often became a re-branding of project-based or problem-based learning that connected science content to engineering design challenges and everyday contexts, without fully addressing how evidence, modelling, design criteria, and values function differently across STEM domains.

These findings resonate with Park and colleagues' curriculum analysis, suggesting a systemic pattern: policy and professional development frequently encourage integration and authenticity, but pay less attention to the epistemic and socio-ethical underpinnings of STEM disciplines. As a result, learners may engage in attractive, hands-on STEM activities yet retain naïve images of science as linear method, engineering as "making things," mathematics as calculation, and technology as gadgets, precisely the images that NoSTEM scholarship seeks to complicate.

ADI as a pedagogical spine for NoSTEM

Against this backdrop, ADI offers a structured way to foreground NoSTEM by placing investigation, evidence-based argumentation, critique, and reflection at the centre of STEM learning. In the empirical literature, ADI has been shown to improve students' argumentation quality, conceptual understanding, and scientific reasoning compared with traditional confirmatory laboratory work, including in interdisciplinary and technology-rich contexts.

From a NoSTEM perspective, several features of ADI are particularly significant. First, its insistence that students articulate explicit claims, support them with evidence, and connect the two through warrants makes visible that knowledge in STEM is not simply "found" but argued for, criticised, and revised. This directly targets epistemic aspects of NoSTEM such as theory–data relations, standards of evidence, and the role of uncertainty.

Second, when ADI tasks are framed around interdisciplinary, real-world problems—urban air quality and transport, school energy systems, food and biotechnology—the model naturally requires learners to coordinate scientific concepts, mathematical representations, technological constraints, and engineering design criteria. In such ADI-based integrated STEM units, students must justify why one design or policy option is preferable to another, drawing simultaneously on empirical data (science), models and calculations (mathematics), feasibility and performance considerations (engineering), and usability, cost, or equity concerns (technology and socio-ethics).

Structured peer critique and whole-class argumentation then surface differing assumptions, values, and trade-offs, providing fertile ground for explicit discussion of NoSTEM dimensions: How did different kinds of evidence function in our arguments? Which values did we privilege when judging solutions? In what ways did mathematical models support or constrain our reasoning?

Moreover, ADI's reflection phases can be deliberately designed to prompt meta-level articulation of disciplinary similarities and differences, in line with FRA. Students might be asked, for example, to compare how they justified a scientific explanation versus an engineering design, or to reflect on how mathematical representations changed what they could see or argue about a problem. In this way, ADI does not merely embed NoSTEM implicitly within activity, but can be used to structure explicit reflection on the epistemic, methodological, social, and ethical features of STEM.

Alignment with NEP 2020 and the Indian policy context

In India, NEP 2020 calls for a shift from rote, textbook-centred teaching to experiential, inquiry-driven, and multidisciplinary learning that cultivates scientific temper, critical thinking, and problem-solving skills across the school years. Complementary policy and curriculum documents, including the National Curriculum Framework (NCF) 2005, already emphasise connecting science to everyday life, promoting hands-on investigations, and integrating environmental and socio-scientific issues into science teaching.

However, implementation studies and classroom observations frequently report that "activities" remain disconnected from deeper reflection on how scientific and technological knowledge is generated and used, and that high-stakes examinations continue to reinforce content-heavy, procedural approaches. Framing NoSTEM as an explicit curricular aim, supported by ADI as a pedagogical spine, offers one way to operationalise NEP 2020's broad aspirations in concrete classroom practice.

ADI-based NoSTEM units can be designed around locally relevant issues—air pollution in Indian cities, water quality and conservation, energy transitions, digital infrastructures and data privacy, so that students engage with interdisciplinary STEM content while also interrogating the epistemic and ethical dimensions of these problems. Such units align with NEP 2020's emphasis on multidisciplinary, project-based learning and socio-scientific issues, but add a sharper focus on argumentation, evidence evaluation, and value reasoning as central to scientific temper.

For teacher education, this implies that professional learning should not only familiarise teachers with ADI routines and integrated STEM design, but also with NoSTEM and FRA as conceptual tools for analysing their own practice. As Dare and colleagues show, even after professional development, many science teachers continue to see mathematics and technology primarily as tools, and engineering primarily as generic design; addressing these conceptions will require sustained opportunities for teachers to engage in ADI themselves around rich STEM problems, to analyse classroom discourse for epistemic moves, and to co-design tasks that make disciplinary and interdisciplinary practices explicit.

In contexts like India, where class sizes are large and exam pressures intense, such professional development must also attend to practical constraints, offering adaptable ADI-NoSTEM task structures and assessment approaches that are feasible within existing systems while gradually reshaping what counts as valued STEM learning.

Illustrative Classroom Implications for Teaching NoSTEM through ADI

Example 1: Urban air quality and transport choices

A secondary integrated STEM unit might focus on urban air quality and mobility options. Students could:

- collect or access air quality data (e.g., particulate matter near roads versus green areas);
- model exposure patterns using simple statistics and graphs;
- investigate health and environmental impacts of different transport modes; and
- design and argue for interventions (e.g., improved public transport, cycling infrastructure, emission norms).

Within an ADI framework, students would conduct investigations or data analyses, then construct arguments comparing proposed interventions based on multiple forms of evidence (scientific data, cost estimates, user acceptability) and value-based criteria (equity, safety, sustainability). Small-group and whole-class argumentation would surface differing assumptions about risk, responsibility, and feasibility, and reflection tasks would prompt students to articulate what the process reveals about how STEM knowledge, design, and values interact in real-world policy choices, core aspects of the Nature of STEM.

Example 2: Energy systems and school sustainability
Another unit could address school energy use and renewable options. Students might audit electricity consumption, model impacts of efficiency measures, and investigate potential benefits and limitations of solar panels or other technologies for the school context. Through ADI, learners would build and critique arguments about which combination of measures (efficiency upgrades, behaviour changes, technology adoption) best meets criteria such as cost, carbon footprint, reliability, and equity.

Here ADI structures support understanding that engineering decisions rely not only on technical feasibility but also on economic and social constraints, and that different stakeholders may prioritise different criteria. Reflection could explicitly target NoSTEM by asking students to compare how scientific, technological, engineering, and mathematical considerations contributed to their final recommendations, and how this process differs from a simplistic "apply formula, get answer" view of STEM.

Implications for Curriculum, Teacher Education, and Research

Curriculum design
For curriculum developers, this analysis suggests that ADI can serve as a design spine for units intended to foster NoSTEM understanding. Tasks should be crafted to:

- involve authentic, open or semi-open problems with no single correct solution;
- require coordination of concepts and practices from at least two STEM disciplines;
- foreground the need to justify claims or designs under evidential and value-based constraints; and
- allocate time for explicit reflection on what the inquiry reveals about the Nature of STEM.

Such design can be aligned with NEP 2020's emphasis on experiential, inquiry-based learning and integrated projects, while giving clearer epistemic focus to the "scientific temper" and critical thinking the policy seeks to cultivate.

Teacher education and professional learning
Implementing ADI for NoSTEM requires teachers to have not only strong content knowledge, but also pedagogical content knowledge for argumentation and integrated STEM. Teachers need support in:

- designing ADI tasks that genuinely integrate STEM practices;
- facilitating productive argumentation, especially in large or exam-driven classes;
- assessing the quality of students' arguments and NoSTEM understandings; and
- handling socio-ethical discussions that may be sensitive or value-laden.

Professional development programs can model ADI by having teachers themselves engage in argumentation about STEM-related issues, analyse classroom video of ADI lessons, and collaboratively design and trial ADI-based STEM units aligned with local curricula and NEP 2020 reforms. This approach is consistent with findings that sustained, practice-focused professional learning is necessary for successful integrated STEM implementation.

Research directions
The emerging literature on NoSTEM and integrated STEM points to several research needs that intersect with ADI:

- developing instruments (such as recently proposed NoSTEM assessment tools) to measure how students' NoSTEM understandings develop in ADI-based units;
- investigating how different ADI task designs (e.g., more design-focused versus more data-focused) emphasise particular NoSTEM dimensions;
- comparing student outcomes in ADI-based NoSTEM instruction across cultural and policy contexts, including Indian classrooms implementing NEP 2020 and
- analysing classroom discourse to understand how epistemic, social, and ethical aspects of STEM are negotiated in ADI discussions.

Such research can help refine both ADI and NoSTEM frameworks, ensuring they are sensitive to contextual realities while retaining theoretical coherence.

Conclusion

This paper advances the argument that, in the contemporary educational regime, teaching the Nature of STEM is an essential goal of school STEM education, not an optional enrichment. In a world marked by complex socio-scientific issues, rapidly evolving technologies, and calls for critical, informed citizenship, learners must understand how STEM knowledge is produced, justified, and deployed in interdisciplinary and value-laden contexts. Drawing on current NoSTEM and integrated STEM literature, the paper has clarified how NoSTEM extends and complements the Nature of Science tradition, and why it is particularly relevant in policy contexts such as India's NEP 2020.

Against this backdrop, Argument-Driven Inquiry is proposed as a theoretically compatible and empirically supported pedagogy for teaching the Nature of STEM. By organising classroom activity around investigation, evidence-based argumentation, peer critique, and reflection in interdisciplinary problem settings, ADI can make visible the epistemic, methodological, and socio-ethical dimensions of STEM practices.

The illustrative classroom examples and implications for curriculum and teacher education suggest avenues for embedding NoSTEM aims into everyday STEM instruction rather than treating them as add-ons. Future work should systematically study NoSTEM learning outcomes in ADI-based environments, particularly in diverse contexts such as Indian schools implementing NEP 2020, to further refine both the theoretical and practical contributions of this approach.

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