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Students' pre-instructional reasoning about evolution: interactions among conceptual, epistemic, and positioning dimensions

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ABSTRACT

Students' engagement with biological evolution remains challenging due to conceptual demands and sociocultural influences. Research suggests that engagement is shaped not only by scientific knowledge but also by epistemic trust, evaluation of evidence, scientific authority, and learners' positioning toward scientific explanations. However, little qualitative work has examined how these factors interact prior to instruction. This study investigates how upper secondary students reason about evolutionary explanations before formal instruction. A qualitative descriptive approach was used, based on semi-structured interviews with 25 Grade 12 biology students in western India. Thematic analysis identified dominant reasoning patterns and epistemic positions. Findings reveal fragmented conceptual understanding, scale-dependent acceptance of evolutionary claims, and varied reliance on authority and evidence. Many students expressed conditional acceptance grounded in epistemic trust, while others negotiated tensions between scientific explanations and personal belief frameworks through reconciliation or resistance. Students also articulated preferences for instructional approaches emphasising evidence, dialogue, and conceptual clarity. These findings show how conceptual reasoning, epistemic evaluation, and epistemic positioning interact in shaping students' reasoning prior to formal instruction, with implications for evolution education. The study provides a process-oriented account of how these dimensions interact prior to instruction, a phase underexplored in evolution education research.

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Introduction

Students' understanding of biological evolution remains a persistent challenge in science education worldwide. Although evolution serves as a unifying framework in biology, it is often conceptually demanding and socially contested. Students often enter classroom instruction with fragmented understandings and persistent misconceptions that coexist with scientific terminology and alternative explanatory frameworks (Beggrow & Nehm, 2012; Bishop & Anderson, 1990; Demastes et al., 1995). Research indicates

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that understanding and acceptance of evolution are influenced by multiple factors, including epistemic views and scientific authority (Glaze & Goldston, 2015; Kampourakis, 2014), as well as perceived compatibility with belief systems (Barnes et al., 2021b; Miller et al., 2021), and that conceptual knowledge alone does not ensure acceptance.

Students often rely on intuitive explanatory frameworks, including teleological and essentialist reasoning, and struggle to integrate variation, inheritance, and natural selection into coherent explanations (Beggrow & Nehm, 2012; Furrow & Hsu, 2019; Kampourakis, 2020).

Students' expectations about scientific evidence also shape their engagement with evolution. While small-scale changes are often accepted, large-scale processes such as speciation and deep time are frequently met with scepticism (Gregory, 2009). Fossil evidence is sometimes viewed as incomplete, reflecting misunderstandings about inferential reasoning in historical sciences (National Academy of Sciences, 1998).

Acceptance of evolution is also shaped by how students negotiate personal belief frameworks in relation to scientific knowledge. Learners may understand evolutionary explanations while adopting different epistemic stances toward their validity (Smith & Siegel, 2016). Such reasoning reflects socioscientific processes in which evidence, values, and worldview commitments interact within broader sociocultural contexts beyond religious affiliation (Oliveira et al., 2022; Sadler & Zeidler, 2005).

Within the Indian context, population-level surveys suggest relatively high public acceptance of evolution despite widespread religious identification, with approximately 68.5 percent of respondents reporting acceptance of human evolution (Bast & Tahilramani, 2018). This suggests that, unlike in some Western contexts, evolution is not widely framed as a controversial issue in the Indian educational context, although students may still engage with it through personal and cultural interpretations. However, such findings reveal little about how acceptance is constructed within classroom settings. At the school level, evolutionary theory is typically emphasised in senior secondary biology curricula, within national curriculum frameworks, where formal engagement with evolutionary mechanisms and evidence is concentrated at the higher secondary stage (National Council of Educational Research and Training, 2020, 2023). This curricular sequencing may restrict earlier opportunities for students to develop coherent conceptual and epistemic frameworks related to evolutionary reasoning. Consequently, learners may enter higher secondary instruction with fragmented knowledge shaped by limited exposure rather than sustained conceptual progression.

In addition, classroom interactions in many Indian educational contexts are often characterised by strong respect for teacher authority and teacher-directed, discipline-oriented practices that limit opportunities for student voice and the expression of alternative conceptions, which are widely documented in science education research (Guerra-Reyes et al., 2024; Kumar, 2019) and reflected in national curriculum frameworks (NCERT, 2005). Such patterns may shape how students evaluate scientific knowledge, fostering epistemic trust while potentially limiting critical engagement with evolutionary explanations.

However, existing research has largely examined these factors in isolation or through quantitative models, leaving limited understanding of how they interact within students' reasoning prior to instruction. Taken together, this research highlights persistent conceptual, epistemic, and positioning-related challenges in evolution education and points to an underexplored phase: students' reasoning prior to formal classroom instruction (Dunk et al., 2019; Fiedler et al., 2024).

Prior research using integrated quantitative models has shown that evolution acceptance is influenced by factors such as knowledge, religiosity, and epistemological variables (Dunk et al., 2017), but such approaches do not capture how these dimensions are constructed and negotiated within students' reasoning at this stage.

To address this gap, the present study draws on an integrated theoretical perspective combining conceptual change theory, socioscientific perspectives, and epistemic cognition, with particular emphasis on students' epistemic evaluation and positioning as an integrative lens. Conceptual change research in evolution education suggests that learners may hold internally coherent explanatory frameworks that shape how new information is interpreted (Demastes et al., 1995; Greene, 1990). From this perspective, misconceptions reflect structured conceptual ecologies rather than isolated errors, and learning evolution requires reorganisation of existing explanatory systems, including intuitive teleological and essentialist reasoning (Sinatra et al., 2008).

Complementing this view, socioscientific issues perspectives situate evolution learning within broader contexts in which scientific claims are interpreted alongside personal values, identity commitments, and social meanings (Sadler, 2009; Zeidler et al., 2001). This perspective helps illuminate how students negotiate perceived tensions between evolutionary explanations and personal belief frameworks and how they articulate expectations regarding classroom discussion, evidence, and dialogue.

Epistemic cognition perspectives further emphasise that learners actively evaluate knowledge claims, sources of authority, and standards of evidence when interpreting scientific explanations. From this standpoint, acceptance of evolution is understood not simply as a function of conceptual knowledge but as an interpretive position grounded in judgments about credibility, certainty, and legitimacy of scientific explanations (Sadler & Zeidler, 2004).

Taken together, these perspectives frame students' engagement with evolution as a multi-layered process involving conceptual restructuring, sociocultural negotiation, and epistemic evaluation. In this study, acceptance of evolution is therefore treated as an epistemic position rather than a binary outcome, encompassing conditional acceptance, reconciliation, compartmentalisation, or rejection depending on how learners interpret scientific evidence in relation to personal belief frameworks (Smith & Siegel, 2016). Specifically, this study examines how conceptual, epistemic, and positioning dimensions interact in students' reasoning prior to instruction, offering a process-oriented qualitative account of these interactions. The relationships among these perspectives are synthesised in an integrated framework (Figure 1).

The study focuses on students' reasoning before formal teaching begins as part of a broader instructional investigation. The aim is to examine how students perceive and explain evolutionary ideas before formal teaching in order to establish a baseline for analysing their reasoning and patterns of acceptance. The research questions collectively examine different dimensions of students' reasoning about evolutionary explanations prior to instruction. Guided by this framework, the study addresses the following research questions:

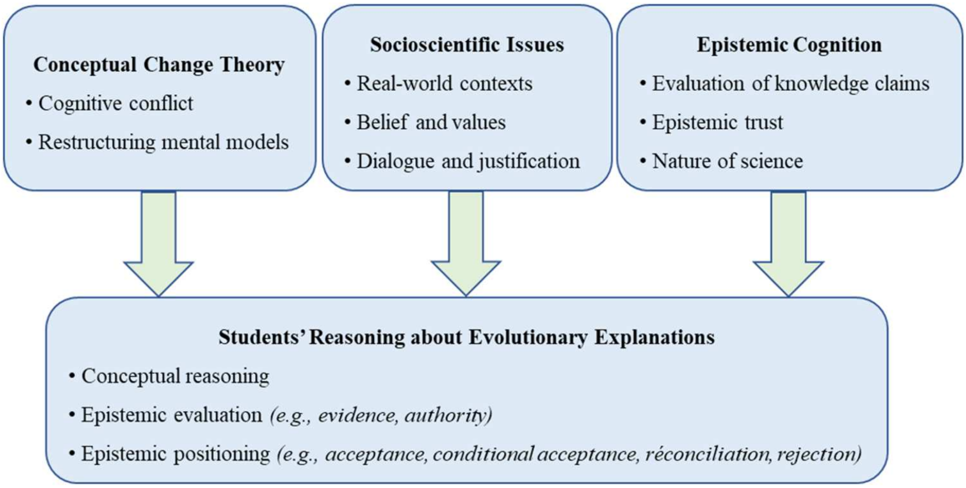

Figure 1. Integrated framework of conceptual, epistemic, and positioning dimensions in students' reasoning about evolution.

- How do upper secondary students reason about evolutionary explanations prior to formal instruction?
- What epistemic factors, including evaluation of evidence, authority, and belief-related considerations, are reflected in students' reasoning about evolutionary explanations?
- How do students position themselves epistemically in relation to evolutionary explanations, including patterns of acceptance, conditional acceptance, reconciliation, or rejection?

Materials and methods

Research design

This study adopted a qualitative descriptive research design to explore upper secondary students' pre-instructional conceptions of evolution, patterns of acceptance and scepticism, and belief-influenced reasoning. In this study, the term 'pre-instructional' refers specifically to the period prior to formal, structured instruction on evolution at the higher secondary (Grade 12) level.

The study aimed to describe how students reason about evolutionary explanations prior to formal instruction, including their conceptual, epistemic, and positioning dimensions.

Participants and setting

The study involved 25 Grade 12 students (typically aged 16-18 years) enrolled in upper secondary within a state-level higher secondary system in western India. Although students had encountered basic evolutionary ideas in earlier schooling, they had not yet received systematic and conceptually integrated instruction on evolutionary mechanisms and supporting evidence at this stage. Accordingly, their responses reflect reasoning shaped by prior exposure rather than by comprehensive engagement with evolutionary concepts.

Participants were drawn from one higher secondary institution in an urban setting in western India. Although all students were enrolled within the same higher secondary system at the time of data collection, they had completed prior schooling through different institutional contexts, resulting in differences in academic orientations, prior exposure, and personal perspectives.

Purposive sampling was used to capture variation in students' prior exposure to evolution and acceptance positions, informed by pre-test responses. The pre-test provided an initial indication of acceptance and exposure levels, guiding the inclusion of diverse perspectives. The interview participants were selected from a broader pre-test cohort of 229 students (115 experimental and 114 control). The interview sample ($n = 25$) included 14 students from the experimental group and 11 students from the control group. Although the broader study included pre-test measures of evolution acceptance, the present paper focuses exclusively on qualitative interview data collected prior to instruction. Participants were selected to capture variation in perspectives relevant to the study aims.

Interview protocol

Data collection relied on a semi-structured interview guide containing 32 exploratory questions addressing students' conceptual understanding of evolution, evidentiary reasoning, acceptance or scepticism toward evolutionary explanations, belief-influenced perspectives, and instructional expectations.

The interview guide was reviewed by two biology educators to ensure conceptual relevance and clarity. It was informed by prior research on students' understanding and acceptance of evolution, particularly studies emphasising the distinction between these constructs and the role of belief-related and epistemic factors (e.g. Barnes et al., 2022; Dunk et al., 2017), and was designed as an original set of open-ended questions rather than an adaptation of a single existing instrument.

Questions were designed to explore students' reasoning. The semi-structured format allowed flexibility to probe participants' explanations while maintaining alignment with the conceptual, socioscientific, and epistemic dimensions guiding the study.

The interview questions were organised into six thematic categories: (a) understanding and acceptance of evolution, (b) sociocultural and religious influences, (c) scientific evidence and reasoning, (d) microevolution and macroevolution, (e) human evolution and perceived complexity, and (f) educational challenges and instructional needs. Questions were iteratively refined based on expert feedback to enhance clarity.

The full interview guide is provided as supplementary material (Appendix A).

Data collection procedures

Data were collected prior to formal instruction on evolution at the higher secondary level through individual and small-group semi-structured interviews.

A total of nine individual interviews were conducted, including six telephone interviews and three in-person interviews. The remaining 16 participants took part in six small-group interviews conducted in person, with group sizes ranging from two to four participants. The interviews were conducted over a one-week period in June 2025 (21-25 June).

Group interviews facilitated interaction and elicited socially situated reasoning, allowing students to respond to and build upon each other's ideas, while individual interviews provided more detailed and reflective accounts, particularly from students representing distinct reasoning patterns or acceptance profiles. During these sessions, the researcher actively facilitated discussion to ensure that all participants had opportunities to contribute and that no single participant dominated the interaction.

Participants were purposively selected based on pre-test responses to capture variation in acceptance levels (high, low, and mixed), interest in evolution, and educational backgrounds. This sampling strategy enabled inclusion of students with varied acceptance positions and backgrounds, supporting exploration of diverse reasoning patterns.

All interviews were audio-recorded with participants' consent and transcribed verbatim. Interview durations ranged from approximately 15–40 minutes for individual interviews and 25–110 minutes for group interviews.

In analysing group interviews, individual responses were considered separately to allow identification of personal reasoning patterns while retaining the contextual influence of peer interaction. Analytic attention focused on students' explanations and justifications, including their use of evidence, reliance on authority, and expressions of belief or doubt. This enabled interpretation of how students reasoned about and evaluated evolutionary explanations. This approach allowed the study to capture both individually articulated reasoning and socially mediated perspectives emerging through group interaction, thereby enriching interpretation of students' epistemic positioning.

Ethical procedures followed in this study are described in the Ethics Statement section.

Data analysis

Data were analysed using reflexive thematic analysis following Braun and Clarke (2006), with an approach that combined inductive coding with theoretically informed interpretation. This allowed patterns to emerge inductively from the data, which were subsequently interpreted using the study's integrated framework of conceptual change, epistemic cognition, and socioscientific issues perspectives.

All transcripts were read multiple times to achieve familiarisation. Initial codes were generated inductively to capture students' explanations, justifications, and evaluative statements regarding evolutionary theory. Coding was conducted at the level of individual meaning units, with responses from group interviews treated as distinct analytic units to preserve participant-level interpretation.

Following initial coding, codes were iteratively reviewed and organised into categories. At this stage, the theoretical framework informed the interpretation of patterns emerging from the data. Specifically, the analysis examined how students' reasoning reflected (a) conceptual understanding and misconceptions (conceptual change perspective), (b) epistemic evaluation of knowledge claims (epistemic cognition), and (c) epistemic positioning in relation to evolutionary explanations, including belief – science negotiation (socioscientific perspective).

Through this iterative process, themes were refined to represent three interconnected dimensions of students' pre-instructional reasoning:

(1) patterns of conceptual reasoning about evolution,
(2) epistemic evaluation of evolutionary explanations, including evidence and authority, and
(3) epistemic positioning in relation to evolutionary explanations (acceptance, conditional acceptance, reconciliation, and rejection).

To further interpret students' reasoning, elements of informal reasoning frameworks (Sadler & Zeidler, 2005) were used as sensitising concepts during the later stages of analysis, following initial inductive coding and theme development. These frameworks informed the interpretation of students' justifications, particularly in relation to evidence use, belief-based reasoning, and attempts at reconciliation. In this way, patterns such as empirical reasoning (evidence-based justification), reconciliatory reasoning (integration of scientific and belief-based perspectives), and belief-dominant (absolutist) reasoning (resistance to evidentiary reconsideration) were interpreted. These orientations were used as interpretive lenses to characterise variation in students' responses rather than as fixed coding categories.

Themes were refined through constant comparison across transcripts, with attention to both convergence and variation in responses. Although some patterns in students' responses appeared to overlap (e.g. epistemic trust and belief-anchored rejection), these were distinguished based on their different roles in students' reasoning. Epistemic trust reflects how students evaluate the credibility of scientific knowledge through authority and evidence, whereas belief-anchored rejection reflects epistemic positioning shaped by strongly held belief frameworks. The themes were organised into three overarching dimensions, interpreted in relation to the study's integrated framework: conceptual reasoning, epistemic evaluation, and epistemic positioning.

Reflexivity was maintained throughout the analysis. As researchers in science education, we acknowledge that our disciplinary perspectives may influence interpretation; therefore, coding and theme development involved repeated engagement with the data to ensure that interpretations remained grounded in participants' expressed meanings.

Credibility was supported through prolonged engagement with the data and the use of illustrative excerpts to substantiate analytic claims.

Semi-structured interviews enabled in-depth exploration of students' reasoning, as participants were encouraged to elaborate, justify, and reflect on their responses during the interaction. The combination of individual and small-group interviews provided both reflective and interactive contexts, supporting rich qualitative insights into how students articulated and negotiated their understanding. This approach aligns with the qualitative descriptive design of the study, with a focus on generating analytical insight into students' reasoning rather than statistical generalisation.

Results

The analysis identified multiple interrelated themes that characterise students' pre-instructional reasoning about evolutionary theory. These themes were organised into three analytical dimensions derived from the integrated framework (Figure 1): (a) conceptual reasoning, (b) epistemic evaluation, and (c) epistemic positioning in relation to evolutionary explanations. Table 1 provides an overview of the themes along with illustrative excerpts from student responses.

Table 1. Overview of analytical dimensions and subthemes with illustrative excerpts.

Dimension	Subthemes	Frequency (n = 25)	Example
Conceptual Reasoning	Foundational understanding	13	Process of transformation of organism over a long time
	Fragmented conceptual framework	10	Evolution happens suddenly
	Teleological/Lamarckian misconceptions	9	Duck has webbed feet, because they need to swim
	Human evolution misconceptions	5	Humans have evolved from monkeys
	Micro-macro distinction	10	Small changes can take place but I don't believe in speciation
	Conceptual confusion	2	Many concepts are confusing, even the stages of human evolution
Epistemic Evaluation	Trust in scientific authority	15	Theory is not on illusion. It is based on scientific evidence and facts.
	Trust in empirical evidence	12	DNA-based evidence is more convincing
	Reliance on curricular authority	9	I believe things given in textbook are correct and examples given convincing
	Evidential skepticism	8	We haven't got enough fossils of intermediate organisms
	Perceptions of scientist beliefs	5	Scientist may or may not be religious
Epistemic Positioning	Microevolution acceptance	12	I can see changes occurring in the organisms
	Macroevolution acceptance	12	Species change over time
	Rejection of human evolution	6	I don't believe human has evolved; they are as they were before.
	Compatibility	6	Evolution theory goes along with religious text
	Faith conflict	7	I don't believe, as I am firm believer in religion
	Internal conflict	4	It's not wrong to believe that God may have some role. Everyone has their own way to look at the things
	Conditional acceptance	3	I accept 50% of the theory, not completely due to religion
	Cognitive dissonance	3	It's confusing that even scientists bring God in explanations
Instructional Expectations (contextual)	Visual learning	13	Don't explain verbally. Pictures and videos give clarity
	Dialogic discussion	15	Teacher should discuss about both the sides (e.g. different perspectives)
	Cautious or sensitive discussion	8	Teach in such a way that students don't get offended, but discussion on both

Note: Less frequently occurring or overlapping categories (n $\leq$ 2) were excluded from the table for clarity but are referred to in the text where relevant. Conceptual confusion (n = 2) was retained because it represented a theoretically important category related to students' difficulties in integrating evolutionary concepts.

As shown in Table 1, several categories were prominent in students' responses. High-frequency patterns included trust in scientific authority, empirical evidence, and acceptance across evolutionary scales. Conceptual fragmentation and micro–macro distinction issues were also widely observed. In contrast, categories such as conditional acceptance and cognitive dissonance were less frequently expressed.

Conceptual reasoning about evolution

Across the interviews, several students ($n = 13$) demonstrated superficial explanations, while many participants ($n = 10$) also expressed partially coherent but fragmented reasoning about evolutionary processes; these categories were not mutually exclusive. While some participants referred to gradual change and adaptation, their explanations often lacked mechanistic clarity and reflected common misconceptions. For instance, several students expressed ideas such as 'Humans have evolved from monkeys,' as well as questions such as 'If humans evolved from monkeys, why do monkeys still exist?' indicating linear interpretations of evolution. Some students also demonstrated confusion in linking genetics with evolution. For example, some believed that 'only the Y chromosome changes,' or that melanin is present in blood. Others questioned how populations differ if 'all have the same DNA,' while others suggested that traits such as skin colour were not related to evolution but only to DNA. A few participants also provided oversimplified explanations, such as 'Unicellular became complex … natural selection dismissed unnecessary characters,' reflecting partial understanding.

Students also frequently described evolution in terms of need-based or purposeful change, suggesting the persistence of teleological reasoning. A few students also interpreted 'survival of the fittest' in terms of physical strength rather than reproductive success, indicating misunderstanding of evolutionary fitness. A few students attributed their limited understanding to examination-oriented learning.

In addition, several students ($n = 10$) demonstrated difficulty distinguishing between microevolutionary and macroevolutionary processes. While small-scale changes were often recognised, large-scale evolutionary changes such as speciation were perceived as less plausible or more difficult to understand. Confusion also extended to evolutionary timescales, with some students expecting evolutionary change to occur suddenly or within observable timeframes rather than over long geological periods.

Epistemic evaluation of evolutionary explanations

Within this dimension, epistemic trust reflects students' reliance on authority, evidence, and sources of knowledge when evaluating evolutionary explanations. Students evaluated these explanations using factors such as observability and credibility of evidence. Their evaluations were often grounded in confidence in scientists, teachers, and textbooks ($n = 15$), with evolutionary explanations described as credible because they were based on 'scientific facts' or 'evidence.' For instance, one student stated, 'If scientists say it with proof, it must be true,' reflecting reliance on scientific authority as a basis for evaluation. However, acceptance grounded in pedagogical authority did not always correspond with strong conceptual understanding.

Students also expressed varied views about scientists as sources of knowledge. While some participants assumed that scientists are purely rational and non-religious, others believed that scientists could hold personal beliefs without compromising their scientific work. For example, one student remarked that 'a scientist can be religious … maybe they will do *pooja* (a traditional ritual or prayer practice in Indian religious contexts).' These responses suggest that students' evaluations of scientific knowledge are influenced not only by evidence but also by their assumptions about the relationship between science and religion, including how they perceive scientists' personal beliefs.

Evidence-based reasoning was evident in students' evaluation of evolutionary explanations, particularly in their references to different types of evidence. Molecular data such as DNA was frequently regarded as highly convincing, whereas historical evidence such as fossils was more often questioned.

This scepticism was reflected in students' concerns about the adequacy and reliability of fossil evidence ($n = 8$), with some participants noting that 'only 40–80% bones are recovered, so how can scientists classify the species?' and others arguing that 'we haven't got enough fossils of intermediate organisms.' Such responses indicate expectations that scientific explanations require complete and directly observable evidence, particularly for large-scale evolutionary changes.

These doubts were also linked to challenges in understanding historical inference in evolutionary science, with several students expressing uncertainty about how fossil evidence is interpreted and whether such interpretations are reliable. A few students also raised concerns about the possibility of error or disagreement among scientists. In certain cases, scepticism extended to questioning the authenticity or reliability of evidence itself.

Observability emerged as a key evaluative criterion. Students were more likely to accept explanations supported by visible or contemporary examples, such as microbial evolution, while expressing doubt about large-scale evolutionary processes that could not be directly observed. Statements such as 'We haven't seen humans evolving' reflect reliance on direct observation as a standard for acceptance.

In contrast to reliance on authority, some students engaged with the nature of scientific knowledge itself. Several students recognised the role of evidence in supporting scientific claims, noting that 'the theory is supported by evidence' and that scientific explanations are based on research and proof. However, for a few participants, the tentative and evolving nature of scientific knowledge was interpreted as a limitation rather than a strength, leading to reduced confidence in evolutionary explanations.

These patterns suggest that scepticism toward evolutionary evidence may reflect underlying epistemic expectations about certainty, completeness, and visibility of evidence. Such expectations highlight challenges in understanding how scientific knowledge is constructed, particularly in historical sciences where inference plays a central role.

Epistemic positioning in reasoning about evolution

Students' epistemic positioning included acceptance, conditional acceptance, reconciliation, and rejection, reflected in patterns such as acceptance of microevolution, belief-based rejection, and efforts toward compatibility or reconciliation. These patterns align with forms of informal reasoning, including empirical, reconciliatory, and belief-dominant reasoning (Sadler & Zeidler, 2005). These positions were not uniform but varied depending on how students interpreted evidence, personal beliefs, and the scope of evolutionary claims.

A number of students indicated general acceptance of evolution, often grounded in exposure to scientific explanations and perceived credibility of evidence. However, acceptance was frequently partial or conditional. Several participants acknowledged supporting evidence while expressing reservations about specific aspects of the theory. For instance, one student stated, 'I accept 50% of the theory, not completely due to religion,' reflecting a position in which scientific explanations were considered plausible but not fully endorsed.

In some cases, students distinguished between belief systems based on acceptance and science as evidence-based reasoning, while others perceived compatibility between evolutionary explanations and personal belief frameworks. For example, one participant stated, 'Scientifically special creation theory is wrong. I am a person of faith, but it is wrong to bring religion in scientific understanding,' indicating the ability to separate epistemic domains.

Selective acceptance across evolutionary scales was a prominent pattern. Many students accepted microevolutionary changes, particularly in microorganisms, but were hesitant to accept macroevolutionary processes such as speciation and common ancestry. Statements such as 'Small changes can happen, but not new species' illustrate this distinction, suggesting that acceptance was closely linked to perceived observability and familiarity.

Human evolution emerged as the most contested aspect. Several students ($n = 6$) rejected it outright, maintaining that humans are fundamentally distinct from other organisms. Few accepted evolutionary changes in general but excluded humans from this process. These responses indicate that epistemic positioning was not only evidence-dependent but also influenced by sociocultural and belief-related considerations.

In some cases, students demonstrated internally mixed or evolving positions. They expressed agreement with scientific explanations in principle while simultaneously raising doubts or maintaining alternative interpretations. Such responses suggest that students' positions are not fixed but reflect ongoing negotiation between scientific explanations and personal belief frameworks.

Students' epistemic positioning toward evolution was characterised by gradation rather than binary acceptance or rejection, with many occupying intermediate positions shaped by their interpretation of evidence, perceived plausibility, and personal belief contexts.

Students' responses revealed active belief–science negotiation, illustrating how students attempt to reconcile, separate, or prioritise scientific and belief-based explanations rather than simply accepting or rejecting evolutionary theory.

A prominent pattern was reconciliation-based reasoning, in which students accepted evolutionary explanations while maintaining belief in a higher agency. For example, some participants explained that 'God created through nature' or that 'God made the process, evolution just explains how,' indicating attempts to align scientific mechanisms with belief-based interpretations. These responses suggest that students did not necessarily perceive science and belief as mutually exclusive, but instead sought ways to position them as complementary.

Few students explicitly distinguished between the domains of science and religion, describing science as addressing 'how' questions and belief systems as addressing 'why' or purpose-related questions. This distinction enabled some participants to accept evolutionary explanations while retaining personal belief commitments, reflecting compartmentalisation as a strategy for managing potential conflict.

At the same time, other students experienced tension between scientific and belief-based explanations. Some anticipated that evolutionary theory might conflict with religious views or affect personal or community sentiments, even when they themselves expressed partial acceptance. These responses indicate that belief–science negotiation was not only cognitive but also shaped by social and cultural contexts.

In contrast, a smaller group of students demonstrated belief-anchored rejection, where belief systems functioned as fixed epistemic frameworks resistant to revision. Statements such as 'Scriptures never change but science keeps changing' reflect a view of scientific knowledge as uncertain and belief-based knowledge as stable and authoritative. In such cases, students indicated that they would reject evolutionary explanations regardless of evidence, suggesting limited openness to alternative epistemic factors.

Together, these patterns highlight that engagement with evolution extends beyond conceptual understanding to include broader epistemic and sociocultural processes.

Instructional expectations and learning support for evolution (contextual findings)

Students emphasised the need for instructional approaches that support conceptual clarity. Most students acknowledged the importance of learning evolution, linking it to conceptual clarity and scientific understanding. Some also emphasised its relevance beyond examinations, particularly in explaining biodiversity and long-term biological change.

Students expressed curiosity about broader evolutionary questions, indicating interest despite limited conceptual understanding. However, this perceived importance did not consistently translate into engagement, as a few participants described the topic as unengaging or relevant only to specific academic goals. For example, one student described the chapter as 'boring,' indicating limited engagement despite acknowledging its importance.

A prominent expectation was the use of concrete evidence and examples ($n = 13$) to support learning. Students frequently indicated that exposure to 'proof,' such as fossils, experiments, or observable examples, would enhance both understanding and acceptance of evolutionary explanations. For instance, several participants noted that if teachers 'show proofs' or 'teach with evidence,' students would be more likely to understand and accept the theory.

Visualisation and multimodal teaching approaches were also strongly preferred. Participants suggested that videos, images, and demonstrations would make abstract concepts more accessible, particularly for processes that cannot be directly observed. These preferences reflect difficulties in understanding long-term and large-scale evolutionary changes through verbal explanation alone.

Discussion-based learning emerged as another important instructional expectation. Many students expressed the need for classroom dialogue that allows exploration of different viewpoints, including scientific and belief-based perspectives. Some participants indicated that such discussions could help clarify doubts and reduce confusion, while others emphasised the importance of teachers managing these discussions sensitively to avoid discomfort among students with differing belief systems.

Students also linked their current conceptual difficulties to prior instructional experiences. Several participants reported limited exposure to evolution in earlier grades or described previous learning as focused primarily on examinations rather than understanding. Statements such as 'from childhood we are trained to learn only for exam' suggest that surface-level engagement may have contributed to fragmented conceptual frameworks.

Several students expressed curiosity about how scientific knowledge is developed, including how scientists construct and validate theories. This indicates potential for engaging learners in epistemic aspects of science learning.

Effective evolution instruction should integrate evidence-based explanations, visualisation, and structured dialogue, while also addressing students' prior knowledge, misconceptions, and belief-related concerns. Such approaches may support deeper conceptual understanding and more informed engagement with evolutionary explanations.

Discussion

The findings indicate that students' engagement with evolutionary explanations prior to formal instruction at the upper secondary level is context-dependent and shaped by interactions among conceptual understanding, epistemic evaluation, and epistemic positioning.

The findings challenge the assumption that students' engagement with evolution can be understood as stable acceptance or rejection. Instead, they reveal that students' reasoning is selectively applied across different evolutionary contexts, shaped by how they interpret evidence, scale, and explanatory scope.

Addressing the first research question, students' reasoning prior to instruction is shaped by fragmented and intuitive explanatory frameworks.

Teleological and Lamarckian reasoning were especially prominent, with students frequently framing evolution as need-driven or purposeful and interpreting 'survival of the fittest' in terms of strength or size. These patterns reflect intuitive cognitive biases, including essentialist and teleological reasoning, which influence how learners interpret biological change and evolutionary processes (Coley & Tanner, 2012; Sinatra et al., 2008). Such reasoning frameworks tend to prioritise organism-level transformation over population-level mechanisms (Bardapurkar, 2008) and align with an intuitive design stance in interpreting biological change (Kampourakis, 2020). From a conceptual change perspective, these patterns represent structured explanatory frameworks rather than isolated misconceptions, shaping how learners interpret biological change. As Demastes et al. (1995) argue, fragmented understanding constrains learners' ability to connect variation, inheritance, and natural selection into coherent explanatory systems. These patterns also included confusion in linking genetic mechanisms with evolutionary processes, reflecting limited understanding of how variation and inheritance contribute.

A key conceptual difficulty involved distinguishing between microevolution and macroevolution. While small-scale changes were often accepted, speciation, common ancestry, and deep-time evolution generated scepticism. This selective acceptance reflects difficulties with population-level reasoning and inferential thinking about historical processes (Beggrow & Nehm, 2012). In some cases, students also expected complete or direct evidence, indicating challenges in understanding the inferential nature of evolutionary science. Misinterpretations of human evolution, particularly linear narratives suggesting direct progression from monkeys, further indicate resistance to branching evolutionary models (Gregory, 2009).

Students' conceptual difficulties were shaped by pre-instructional educational experiences, including limited exposure to evolution, examination-driven learning, and emphasis on memorisation. Examination-oriented learning shaped what students considered important, with evolution often approached instrumentally rather than conceptually, reinforcing superficial engagement (Glaze & Goldston, 2015; Kampourakis, 2014). This suggests a need to emphasise its real-world relevance to support deeper engagement and understanding (Glaze & Goldston, 2015). Expectations that evolutionary change should be rapid or directly observable indicate limited engagement with geological timescales and scientific inference.

Despite these conceptual limitations, many students recognised evolution as an important domain requiring conceptual understanding rather than rote memorisation. However, this perceived importance did not consistently translate into meaningful engagement, reflecting a disconnect between recognition of relevance and motivation to learn. Their perceptions of relevance appeared to draw on prior exposure to evolutionary ideas and general science learning, including references to biodiversity, extinction, and long-term biological change. This suggests that students may appreciate the significance of evolution even when their understanding remains incomplete (Sadler, 2009; Zeidler et al., 2001).

Some students also expressed curiosity about evolutionary processes and their explanatory scope, indicating emerging engagement despite limited conceptual clarity. At the same time, some students viewed evolution as abstract or relevant only to specific academic pathways, reflecting assessment-driven orientations toward learning.

With respect to the second research question, students' reasoning reflected epistemic evaluation shaped by epistemic trust in evidence, authority, and belief-related considerations. Students' acceptance extended beyond conceptual knowledge to judgments about credibility and legitimacy. Prior research indicates that perceived conflict between evolution and personal belief systems can strongly influence acceptance, often more than knowledge alone (Barnes et al., 2021b). These patterns reflect socioscientific reasoning processes, where evidence, values, and worldview commitments interact (Fowler & Zeidler, 2016; Sadler & Zeidler, 2005). From an epistemic cognition perspective, these evaluations are shaped by trust, perceived certainty, and compatibility with existing belief frameworks. This pattern may also reflect classroom norms in many Indian educational contexts, where strong respect for teacher authority and teacher-directed practices can reinforce epistemic trust while limiting opportunities for critical engagement.

Large-scale studies show that acceptance is influenced by multiple factors, including education, scientific literacy, and religiosity (Miller et al., 2021), and may coexist with limited conceptual knowledge (Kuschmierz et al., 2021). Recent work indicates that acceptance is shaped by contextual and belief-related factors (Fiedler et al., 2024), with understanding of the nature of science accounting for substantial variation (Dunk et al., 2017). While such models identify key predictors of acceptance, they do not capture how these dimensions interact and are actively constructed within students' reasoning, particularly in pre-instructional contexts.

Many students expressed acceptance grounded in epistemic trust in scientific authority and evidence, although this often coexisted with conceptual gaps (Cavallo et al., 2011; Liu et al., 2011). Students often privileged molecular evidence over fossils, reflecting epistemic preferences shaped by perceptions of technological authority (Glaze & Goldston, 2015). This was also reflected in expectations that scientific explanations require complete and directly observable evidence, particularly in relation to fossil records.

Acceptance was often conditional, particularly where perceived conflict with belief systems was present (Barnes et al., 2021a). Students applied different evidentiary standards depending on scale, showing a preference for directly observable evidence and scepticism toward large-scale evolutionary processes that cannot be witnessed, reflecting distinctions between conceptual understanding, epistemic acceptance, and personal belief (Smith & Siegel, 2016). Recognition of the tentative nature of science sometimes supported epistemic openness; however, in some cases it was interpreted as uncertainty, reducing confidence in evolutionary explanations (Khishfe & Lederman, 2006).

Addressing the third research question, students' epistemic positioning ranged from acceptance to rejection, often involving reconciliation and negotiation. These positions were not discrete but reflected gradations, with many students occupying intermediate or shifting positions.

Belief-mediated reasoning played a central role in shaping students' epistemic positioning, reflecting ongoing negotiation between scientific explanations and personal belief systems. Prior research across diverse contexts shows that perceived conflict between evolution and personal belief systems strongly influences acceptance patterns and is associated with lower acceptance when evolution is framed as conflicting with religious worldviews (Barnes et al., 2020).

Many students adopted reconciliation strategies, framing evolution as compatible with divine agency and drawing on culturally familiar explanations to integrate scientific and belief-based perspectives (Kampourakis, 2014; Zeidler et al., 2001). Others compartmentalised scientific and belief-based explanations into separate domains, enabling coexistence, but limiting integration. A smaller subset demonstrated belief-anchored rejection, where belief systems functioned as fixed epistemic frameworks resistant to revision (Sadler & Zeidler, 2005; Sinatra et al., 2008). These positions highlight the limits of evidence-based persuasion when belief systems function as non-negotiable epistemic anchors.

Importantly, openness to reconsideration distinguished conditional acceptance from epistemic rejection. This was often reflected in selective acceptance across evolutionary scales, with students accepting small-scale changes while questioning large-scale evolutionary processes. The availability of evidence alone did not determine acceptance; rather, epistemic stance mediated how evidence was interpreted.

From a socioscientific perspective, these patterns further illustrate how students engage in reasoning by evaluating evidence, considering multiple perspectives, and making decisions within socioscientific contexts involving scientific explanations and personal belief.

Students expressed scepticism toward evolutionary evidence, particularly fossils, often expecting complete and directly observable proof. This reflects reliance on intuitive credibility criteria such as visibility and certainty rather than scientific standards of inference (National Academy of Sciences, 1998).

Students' assumptions about scientists' personal beliefs also shaped their evaluations, with some viewing scientific objectivity as incompatible with religious faith. Such perspectives indicate a limited understanding of the nature of science and highlight the need to engage with the human and social dimensions of science (Levinson, 2006; Zeidler et al., 2001). These patterns further suggest that limited epistemic trust may constrain engagement with broader socioscientific issues, reinforcing the importance of addressing epistemic reasoning alongside conceptual understanding (Fowler & Zeidler, 2016). This highlights that epistemic evaluation is intertwined with broader worldview assumptions rather than based solely on disciplinary criteria of evidence.

As this study focuses on pre-instructional reasoning, these findings provide a baseline for examining how such patterns may change following instruction. They also suggest that students' reasoning prior to instruction is shaped by the dynamic interaction of conceptual, epistemic, and positioning dimensions rather than isolated factors. Students' engagement with evolutionary theory reflects the interaction of conceptual understanding, epistemic evaluation, and belief-influenced reasoning, rather than a simple progression from knowledge to acceptance.

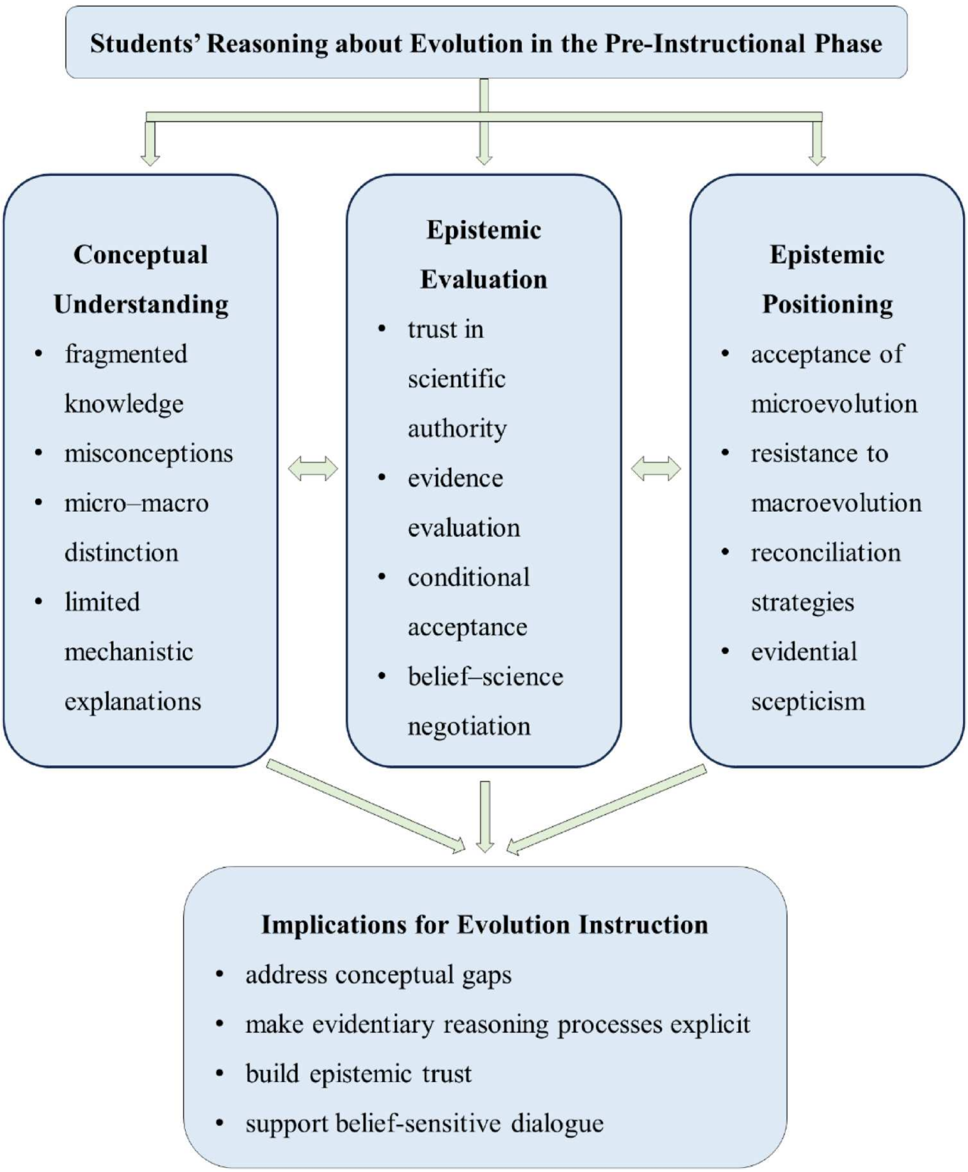

Figure 2. Model of students' reasoning about evolution in the pre-instructional phase.

Implications for evolution instruction

Students' responses regarding instructional approaches should be interpreted as expectations based on pre-instructional reasoning rather than evaluations of actual classroom experiences. Instructional design should address the gap between perceived importance and student engagement and move beyond examination-oriented approaches toward deeper conceptual engagement. Evolution instruction should integrate conceptual understanding, epistemic evaluation, and epistemic positioning. Instruction should support understanding of mechanisms such as variation, inheritance, and natural selection, alongside students' evaluation of evidence, including expectations for direct and observable proof, and their interpretation of scientific explanations in relation to personal belief frameworks. Visualisation and multimodal approaches may further support understanding of processes that cannot be directly observed. Students' instructional preferences reflect what feels accessible and motivating, which may not always support deep conceptual understanding. This highlights the need for instructional approaches that promote epistemic reflection, inferential reasoning, and critical evaluation of evidence.

Instructional approaches informed by socioscientific perspectives may be valuable in this context, as they encourage evidence-based reasoning, perspective-taking, and dialogue around complex scientific issues (Sadler et al., 2007). These preferences for evidence-based and discussion-oriented learning are consistent with research showing that inquiry-oriented and socioscientific approaches support conceptual engagement and epistemic reasoning (Pobiner, 2016; Sadler et al., 2007). Structured classroom discussion can support students in reflecting on scientific knowledge and its development, while promoting critical evaluation of evidence (Khishfe & Lederman, 2006).

The interplay is synthesised in a conceptual model (Figure 2), which demonstrates how conceptual understanding, epistemic evaluation, and epistemic positioning interact dynamically rather than functioning as separate influences.

These implications are intended to inform instructional design at a conceptual level; detailed pedagogical applications are beyond the scope of the present study.

Conclusion

This interview study demonstrates that students' engagement with evolution prior to instruction is shaped by dynamic interactions among conceptual reasoning, epistemic evaluation, and epistemic positioning. Students exhibited scale-dependent acceptance, with greater acceptance of observable changes and scepticism toward large-scale evolutionary processes.

Taken together, these findings address the research questions by showing how students' conceptual reasoning, epistemic evaluation of evidence and authority, and epistemic positioning toward evolutionary explanations interact in shaping pre-instructional engagement.

Their reasoning reflected diverse epistemic positions, including acceptance, conditional acceptance, reconciliation, and rejection, influenced by how they evaluated evidence, authority, and compatibility of evolutionary explanations with their existing belief frameworks. These findings highlight that engagement with evolution extends beyond conceptual knowledge to include how learners interpret and evaluate scientific explanations within broader contexts. Importantly, students' engagement with evolutionary theory reflects the interaction of conceptual understanding, epistemic evaluation, and belief-influenced reasoning, rather than a simple progression from knowledge to acceptance.

This study has broader relevance for evolution education across diverse cultural contexts, where scientific explanations intersect with religious, cultural, and identity-related perspectives (Barnes et al., 2021b; Kuschmierz et al., 2021). These findings are consistent with cross-cultural studies showing that students interpret and negotiate evolution in relation to local belief systems and epistemic perspectives. They underscore the need for instructional approaches that address conceptual understanding alongside students' evaluation of evidence and their positioning toward evolutionary explanations, supporting more informed and reflective engagement with evolutionary theory.

Limitations

These findings should be interpreted in light of certain limitations. The study was conducted with a relatively small, context-specific sample of Grade 12 students from a state-level higher secondary education system in western India, which limits transferability to other contexts. Consistent with qualitative inquiry, the aim was not to produce population-level estimates but to generate analytic insight into patterns of conceptual and epistemic reasoning within a particular setting. The findings are based on interview data capturing students' perspectives at a single pre-instructional time point, and reasoning may shift with formal instruction, peer interaction, or broader learning experiences. Interview responses also reflect how participants articulate ideas in conversational settings and may not fully capture the variability of their reasoning across contexts. Recognising these boundaries supports careful interpretation while highlighting the value of contextually grounded qualitative analysis for examining how learners negotiate conceptual reasoning, epistemic evaluation, and epistemic positioning of evolution. In addition, the inclusion of small-group interviews may have influenced participants' responses through peer interaction or social desirability, potentially shaping how views were expressed. As with all qualitative analysis, interpretations are shaped by the researchers' perspectives, although care was taken to ensure that interpretations remained closely grounded in the data.

Implications and future research

Within these constraints, the study highlights the importance of understanding students' pre-instructional positions as a foundation for effective evolution education. Students' reasoning reveals that conceptual clarity alone is insufficient when epistemic trust and epistemic positioning shape how scientific explanations are interpreted. Designing instruction that explicitly engages with these dimensions may promote more coherent understanding and informed acceptance of evolutionary explanations. This includes engaging students with the nature of scientific evidence, addressing expectations of direct observability, and creating space for dialogue around belief–science relationships. Future research could examine how sustained instructional interventions influence longitudinal changes in students' conceptual understanding, epistemic reasoning, and patterns of acceptance, particularly in relation to evolving trust in scientific knowledge and epistemic positioning. Further research should examine how instructional approaches influence shifts in epistemic evaluation and positioning, particularly in relation to belief–science interactions.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The qualitative data generated for this study are not publicly accessible in order to protect participant confidentiality but can be obtained from the corresponding author upon reasonable request.

AI tools (e.g. ChatGPT) were used for language editing and refinement of the manuscript. The authors take full responsibility for the content.

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