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Misconceptions in Elementary Science Learning: Patterns, Sources, Diagnostic Approaches, and Conceptual-Change Strategies

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Abstract: This narrative review examines misconceptions in elementary science learning, with emphasis on physical science, life science, and Earth-space science, and discusses their sources, diagnostic approaches, and remediation strategies. Peer-reviewed studies and scholarly reviews published mainly between 2015 and August 2026 were synthesized thematically, while selected seminal studies were used to clarify conceptual-change principles. Across the literature, recurring misconceptions include the belief that motion requires a continuing force, heat and temperature are identical, matter disappears during evaporation, plants obtain food directly from soil, electric current is consumed by bulbs, and astronomical phenomena can be explained only from everyday visual impressions. These conceptions are associated with intuitive reasoning, everyday language, oversimplified textbook representations, limited inquiry experiences, and teacher-held alternative conceptions. The literature also shows that conventional right-wrong tests are insufficient to distinguish misconceptions from lack of knowledge or guessing. Multi-tier diagnostic tests, interviews, drawings, concept maps, and confidence-based measures provide stronger evidence. Effective remediation requires making prior ideas explicit and confronting them with evidence through conceptual-change models, Predict-Observe-Explain, discrepant events, inquiry, argumentation, simulations, and contextual experiments. The review concludes that misconception diagnosis should be integrated into routine elementary science assessment and teacher education, with instruction prioritizing explanatory reasoning over factual recall.

Keywords: Conceptual change; Diagnostic assessment; Elementary science; Misconception; Science education

Introduction

Elementary science is expected to build the conceptual foundations that learners will use to interpret natural phenomena, solve everyday problems, and continue learning science at higher levels. At this stage, however, children do not enter the classroom as blank slates. They already possess explanations formed from daily experience, language, family conversations, media, and previous instruction. Some of these explanations are compatible with scientific ideas, while others are stable alternative conceptions that differ from accepted scientific explanations. When an alternative conception is strongly held and repeatedly used to interpret evidence, it may function as a misconception and interfere with later learning.

Misconceptions are educationally important because science concepts are cumulative and interconnected. An elementary learner who interprets force as something that is stored inside a moving object may later struggle with acceleration and Newtonian reasoning. A learner who believes that evaporated water disappears may have difficulty understanding conservation of matter and the water cycle. Similarly, a child who believes that plants obtain their food from soil may memorize the word photosynthesis without

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reconstructing the underlying idea that plants synthesize organic matter using carbon dioxide, water, and light energy. These examples show why a correct final answer alone does not always guarantee scientifically coherent reasoning.

Science education research has documented misconceptions across physical science, life science, and Earth-space science. Reviews of diagnostic research show that frequently misunderstood topics include mechanics, electricity, heat, matter, light, biological processes, and astronomical phenomena (Kaltakci Gurel et al., 2015; Soeharto et al., 2019). In elementary contexts, the difficulty is intensified by the need to transform abstract mechanisms into appropriate age representations without oversimplifying them. Concrete experiences are essential, but a concrete activity that is not accompanied by explanation and reflection can leave the original misconception unchanged.

Indonesian studies provide clear examples of this problem. Nasution et al. (2021) reported a moderate overall level of misconception in force and motion among Grade V students, with particularly high difficulty on spring force. Research on photosynthesis has found misconceptions related to chlorophyll, the timing of photosynthesis, the role of light, and the source of plant food (Febrianti et al., 2023; Zulfa et al., 2025). Electrical-circuit studies likewise show that a substantial proportion of elementary learners can select or interpret circuit representations incorrectly (Maulana et al., 2023). These findings suggest that misconceptions are not isolated errors, but recurring patterns associated with how learners coordinate observation, language, diagrams, and causal explanation.

A key methodological issue is the distinction between an incorrect response and a misconception. A wrong answer can result from guessing, inattention, limited vocabulary, incomplete knowledge, or a stable alternative conception. For that reason, claims about misconceptions should be supported by evidence about students' reasoning, certainty, or repeated response patterns. Reviews of diagnostic instruments emphasize the value of interviews, open-ended questions, concept maps, and multi-tier tests because they reveal more than answer accuracy alone (Kaltakci Gurel et al., 2015; Soeharto et al., 2019). Two-tier tests add a reason to the selected answer, while three- and four-tier formats can incorporate confidence judgments and separate uncertainty from strongly held incorrect reasoning.

The same diagnostic principle applies to teachers and prospective teachers. Elementary teachers mediate children's early encounters with scientific explanations, so teacher-held alternative conceptions can unintentionally be transmitted through examples, analogies, textbook interpretation, and classroom questioning. Research with preservice and primary teachers has shown persistent difficulties in force and motion, astronomy, and other foundational topics, indicating that teacher education must diagnose conceptual understanding rather than assume that completion of previous science courses guarantees scientific conceptions (Anggoro et al., 2019; Trundle et al., 2002).

Addressing misconceptions also requires more than repeating the correct definition. Conceptual-change perspectives propose that learners need opportunities to articulate an initial idea, encounter evidence that exposes its limitations, compare competing explanations, and reconstruct a more coherent model. This process can be supported through discrepant events, inquiry, Predict-Observe-Explain (POE), concept mapping, argumentation, simulations, and conceptual-change texts. The effectiveness of such strategies depends on whether the learning activity makes reasoning visible and requires students to reconcile prediction with evidence rather than merely observe a demonstration (Addido et al., 2022; Anggoro et al., 2019; Rosita et al., 2020).

For elementary science, this issue is closely connected with curriculum design and assessment. Instruction that prioritizes vocabulary recall may conceal unstable reasoning, whereas explanation-based tasks can reveal whether students understand causal relations. Teachers therefore need practical tools to identify conceptions before, during, and after instruction. Diagnostic assessment should be integrated with formative teaching decisions: which representations should be revised, which phenomena require hands-on investigation, and which everyday expressions need scientific clarification.

Recent research also points to the potential of digital media when it is used as a conceptual tool rather than as decoration. Visual simulations, augmented reality, and animated representations can make otherwise invisible processes observable, but their educational value depends on guided prediction, comparison, and explanation. For example, emerging work on photosynthesis highlights the value of augmented representations for reducing the abstraction of plant processes, while studies of conceptual-change multimedia and discrepant events show that technology is most useful when it creates a meaningful conflict between an intuitive prediction and observable evidence (Anggoro et al., 2019; Dzuriansyah et al., 2026).

Accordingly, the present review aims to synthesize recurring misconception patterns in elementary science, identify major sources that sustain these conceptions, examine diagnostic approaches suitable for elementary learners, and discuss instructional strategies that can promote conceptual reconstruction. The review focuses on implications for classroom teachers and elementary

teacher education, with particular attention to evidence relevant to the Indonesian context.

Method

Review Design

This study used a narrative literature review with thematic synthesis. A narrative design was selected because the purpose was to integrate recurring conceptual patterns, diagnostic principles, and instructional implications across heterogeneous science domains rather than calculate a pooled effect size. The review is therefore interpretive and integrative rather than a formal meta-analysis or exhaustive systematic review.

Search and Selection

Relevant literature was identified through keyword-based searches of scholarly indexing services, journal websites, and reference lists. Search terms combined expressions such as elementary or primary science, misconception, alternative conception, diagnostic test, two-tier, three-tier, four-tier, conceptual change, Predict-Observe-Explain, force and motion, photosynthesis, heat, matter, electricity, light, and Earth-space science. Priority was given to peer-reviewed studies published mainly from 2015 to August 2026, while selected earlier seminal studies were retained when they provided foundational evidence about conceptual change or well-established misconception patterns.

Analytical Procedure

The selected literature was read comparatively and coded into four analytical dimensions: (1) science domain and target concept; (2) recurring misconception or alternative conception; (3) source or condition associated with the misconception; and (4) diagnostic or remediation approach. Evidence from elementary students was prioritized. Studies involving preservice or in-service elementary teachers were included when they clarified how teacher conceptions can influence elementary science instruction.

The synthesis did not treat prevalence values from different studies as directly comparable because instruments, grade levels, sample characteristics, and classification rules varied. Percentages are cited only as contextual examples from individual studies. The main emphasis is on recurring patterns that appear across studies and on methodological principles for distinguishing misconceptions from incomplete knowledge.

Table 1. Review Focus and Inclusion Criteria

Dimension	Inclusion / synthesis criterion
Population	Elementary/primary students; preservice or in-service elementary teachers when relevant to classroom transmission.
Science domain	Physical science, matter/heat, life science, light/electricity, and Earth-space science.
Evidence	Diagnostic tests, interviews, drawings, concept maps, intervention studies, and scholarly reviews.
Diagnostic focus	CRI, open-ended tasks, two-tier, three-tier, four-tier, confidence measures, and reasoning evidence.
Intervention focus	Conceptual change, POE/PDEODE, discrepant events, inquiry, argumentation, simulations, and contextual experiments.
Publication focus	Peer-reviewed literature mainly from 2015-August 2026, plus selected seminal conceptual-change studies.

Trustworthiness of the Synthesis

To strengthen interpretive consistency, claims were compared across multiple sources whenever possible, and diagnostic conclusions were weighted more strongly when studies used reasoning-based evidence such as interviews, open-ended explanations, or multi-tier instruments. The review also distinguishes descriptive evidence from causal claims: a reported association between misconceptions and teaching methods does not by itself prove that a particular method caused the misconception.

Ethical Considerations

The study analyzed publicly available scholarly literature and did not involve direct participation by human subjects. No personal student data were collected. Citations are used to attribute conceptual claims and empirical examples to their original sources.

Methodological note: In this review, the term misconception is used when a study provides evidence of an incorrect conception supported by reasoning, confidence, consistency, or repeated diagnostic patterns. A single wrong response is treated more cautiously as an incorrect response or possible conceptual difficulty.

Result and Discussion

Overview of Recurring Misconception Patterns

Across the reviewed literature, misconceptions appear most consistently when the target concept requires learners to infer an invisible mechanism, coordinate multiple representations, or replace an

everyday causal explanation with a scientific one. Force, heat, electric current, particles, photosynthesis, and astronomical motion share this feature. Students can observe effects, such as an object slowing down, water disappearing from an open container, a bulb glowing, a plant growing, or the Moon changing shape, but the causal mechanism is not directly visible. In the absence of structured reasoning, intuitive explanations can become stable conceptual models.

Table 2. Recurrent Misconceptions in Elementary Science and Their Diagnostic Implications

Domain	Typical alternative conception	Diagnostic implication
Force and motion	Motion requires a continuing force; heavier objects necessarily fall faster.	Ask for prediction, reason, and explanation after a discrepant event.
Matter / phase change	Evaporated or dissolved matter disappears; gas is not matter.	Trace matter before and after change; use conservation-focused reasoning.
Heat / temperature	Heat and temperature are the same; heat is a substance stored in objects.	Combine measurements with explanation of energy transfer.
Plants / photosynthesis	Plants obtain food from soil; photosynthesis is only a daytime or green-leaf event.	Use drawings/reasoning about mass source, gases, light, roots, and leaves.
Electricity	Current is consumed by a bulb; a battery sends current from one side only.	Use real and schematic circuits plus explanation of a complete path.
Light	Seeing requires light only at the eye; light reasoning changes with context.	Use two-tier items and ray/path representations.
Earth and space	Moon phases are Earth's shadow; seasons result mainly from Earth-Sun distance.	Coordinate model viewpoint with observations from Earth.
Cross-cutting	Correct vocabulary is used with incomplete or inconsistent causal reasoning.	Require explanation, confidence, and transfer to a new context.

Force and Motion

Force and motion are among the most persistent areas of misconception. Learners commonly infer that a moving object must contain or continuously receive force in the direction of motion, that heavier objects necessarily fall faster, or that force is present only when visible motion occurs. Nasution et al. (2021), using a four-tier test and interviews with Grade V students, reported a moderate overall misconception level and identified particularly strong difficulty with spring force. Similar work with preservice elementary teachers shows that everyday impetus-like explanations can survive into teacher education. Anggoro et al. (2019) found that discrepant events and reflective conceptual-change activities helped preservice teachers revise force-and-motion explanations. These findings indicate that instruction should separate force from motion and require students to reason about interactions, changes in motion, friction, and gravity rather than memorizing definitions.

Matter, Heat, and Changes of State

Misconceptions about matter often arise because particle-level explanations are invisible and because everyday language treats disappearance as nonexistence. Children may state that evaporated water is gone, that matter is destroyed during burning or dissolving, or that gases are not matter because they cannot be seen. Research with primary students on mass and heat shows continuing difficulty in describing properties and transformation processes and in distinguishing heat from temperature (Talib et al., 2025). Such misconceptions are reinforced when instruction presents state changes only as labels—melting, freezing, evaporation, condensation—without tracing where matter goes and what changes at the particle or energy level.

Heat and temperature are also frequently conflated. A warmer object may be described as 'having more temperature' or as containing heat as a material substance. To reconstruct these ideas, elementary instruction should use paired observations, thermometers, controlled comparisons, and explicit language about energy transfer. Prediction tasks are useful because students can state which object they expect to become warmer or cooler, observe the result, and then explain the direction of energy transfer. This sequence helps teachers identify whether a correct measurement is accompanied by a scientifically coherent explanation.

Plants and Photosynthesis

Life-science misconceptions are particularly visible in plant nutrition and photosynthesis. Elementary learners may believe that plants obtain food directly from soil, that roots 'eat' nutrients as food, that photosynthesis occurs only in sunlight during a specific daytime period, or that non-green leaves cannot photosynthesize. Febrianti et al. (2023) identified misconceptions involving the location of chlorophyll, light requirements, and photosynthesis in leaves of different colors. Zulfa et al. (2025), using a three-tier

diagnostic test with Grade VI students, reported that misconceptions were more common than scientifically complete understanding, with especially high difficulty concerning the timing of photosynthesis. These patterns show that students often combine everyday meanings of food with partial memorization of plant structures. Effective instruction should distinguish mineral uptake from food synthesis and link leaf structures, gas exchange, light energy, and organic-matter production in one causal model.

Electricity and Simple Circuits

Simple electric circuits are concrete enough to manipulate but conceptually difficult because current, potential difference, and energy transfer are not directly visible. Students may interpret current as a substance consumed by the bulb, assume that a battery sends current from only one terminal, or misread circuit diagrams when the pictorial arrangement differs from the physical apparatus. Maulana et al. (2023) found substantial misconception among Grade VI students in electrical-circuit content, with difficulty in interpreting illustrated circuits. Diagnostic teaching should therefore combine real circuit construction with multiple representations: schematic symbols, photographs, prediction of bulb behavior, and explanations of a complete conducting path. Merely allowing students to connect components without discussing why the circuit works can leave the original model intact.

Light, Earth, and Space Science

Light and astronomical phenomena create misconceptions because learners must coordinate perspective, scale, and spatial relations. Two-tier diagnostic work on light demonstrates the value of separating an answer from its reason when identifying conceptual understanding (Nasir et al., 2024). In astronomy, learners may explain Moon phases as Earth's shadow, describe the Sun as moving around Earth each day, or attribute seasons primarily to changing Earth-Sun distance. Research on preservice elementary teachers has also documented weak understanding of Moon phases before targeted inquiry instruction (Trundle et al., 2002). These misconceptions are resilient because everyday observation is geocentric. Models and simulations are useful only when students repeatedly connect the model's viewpoint to what an observer on Earth sees.

Sources and Persistence of Misconceptions

The reviewed studies point to several interacting sources. First, intuitive reasoning is efficient for everyday life but can be scientifically misleading. Objects stop after being pushed, so a child infers that motion requires a continuing force; soil is visibly connected to plant growth, so a child infers that soil is plant food. Second, everyday language can blur scientific distinctions, especially words such as force, heat, energy, food, weight, and work. Third, textbook diagrams and simplified teacher explanations may unintentionally suggest inaccurate causal relationships. Fourth, limited practical experience can prevent learners from testing an intuitive idea against evidence.

Teacher knowledge is another important source. A misconception held by a teacher can shape examples, questions, analogies, and feedback. This is especially critical in elementary education because generalist teachers teach multiple science domains and may have uneven content preparation. Studies with preservice elementary teachers show that targeted conceptual-change activities are needed even at university level (Addido et al., 2022; Anggoro et al., 2019). Teacher education should therefore include diagnostic concept inventories and explanation-based tasks before students design elementary lessons.

Misconceptions also persist because correct answers can coexist with incorrect reasoning. A learner may memorize that 'plants make their own food' yet still believe that most plant mass comes from soil. Another may know that Earth revolves around the Sun but still explain seasons through distance. These mixed knowledge states are difficult to detect with conventional multiple-choice tests. The instructional consequence is that teachers should ask students to justify, draw, compare, predict, and revise rather than relying exclusively on selected-response accuracy.

Diagnostic Assessment in Elementary Science

Diagnostic assessment should identify not only whether an answer is correct but how strongly the learner holds the underlying explanation. Kaltakci Gurel et al. (2015) and Soeharto et al. (2019) show that interviews, open-ended questions, and multiple-tier instruments each provide different forms of evidence. Interviews are rich but time-consuming; open-ended items reveal language and causal reasoning but require careful scoring; two-tier tests combine answer and reason efficiently; three- and four-tier tests can add confidence judgments that help distinguish a stable misconception from uncertainty or guessing.

For elementary learners, diagnostic tools should use accessible language and concrete contexts. Pictures, drawings, card sorting, demonstrations, and short oral explanations can reduce reading-load effects. A teacher might ask a child to predict which of two objects will fall first, explain why, observe a demonstration, and then reconsider the explanation. In photosynthesis, students can draw where plant mass comes from and label the role of roots, leaves, air, water, and light. In electricity, learners can select which circuit will light a bulb and

explain the path through which the circuit must be complete. Such tasks generate evidence that is immediately useful for instruction.

Diagnostic classification must also be cautious. A high-confidence wrong answer supported by a consistent reason is stronger evidence of misconception than a low-confidence wrong answer. Conversely, a correct answer with an incorrect reason may indicate partial understanding or guessing. Taşçı (2024) and Nasir et al. (2024) illustrate why reasoning tiers are important when assessing primary-level biology and light concepts. Classroom teachers do not need complex psychometric instruments for every lesson, but they should adopt the principle that reasoning and confidence matter.

Conceptual-Change and Remediation Strategies

The strongest common principle across remediation studies is that learners must actively compare their prior explanation with evidence. Conceptual-change teaching does not simply tell students that an idea is wrong. It first makes the existing conception explicit, then creates dissatisfaction with its explanatory power, introduces a scientifically intelligible alternative, and allows learners to test whether the new model is more useful. Addido et al. (2022) reported improved conceptual understanding among preservice teachers through a conceptual-change model, while Anggoro et al. (2019) demonstrated the value of discrepant events in revising force-and-motion conceptions.

POE and related strategies are particularly suitable for elementary science because they organize learning around a visible reasoning cycle. Students predict an outcome, observe a phenomenon, and explain agreement or conflict between prediction and evidence. Rosita et al. (2020) reported conceptual change among primary students using POE in the context of dissolving substances. The important feature is not the acronym itself but the requirement that students commit to an initial explanation and then revise it. Teachers should record predictions before the demonstration; otherwise, students may simply accommodate the observed result without recognizing the inconsistency in their original model.

Concept maps, argumentation, and conceptual-change texts can strengthen the explanation phase. Concept maps make relationships among concepts visible, while argumentation requires claims to be supported with evidence and reasoning. Simulations and augmented reality can support phenomena that are too small, fast, large, or inaccessible for direct observation. Recent work on elementary photosynthesis suggests that augmented representations can help address the abstract nature of the process (Dzuriansyah et al., 2026). However, technology should be embedded in guided questions; animation alone can create a new superficial representation without conceptual reconstruction.

Implications for Teachers and Teacher Education

For classroom teachers, misconception-sensitive science teaching begins before explanation. A short diagnostic prompt at the start of a topic can reveal what students already believe and can guide the choice of demonstrations, analogies, and questions. During instruction, teachers should use multiple representations and repeatedly ask students to explain causal relationships. After instruction, the same conceptual prompt can be revisited to determine whether reasoning has changed. This approach turns assessment into part of teaching rather than an activity used only to assign scores.

For teacher education, conceptual understanding and pedagogical content knowledge should be developed together. Prospective elementary teachers need experience diagnosing children's ideas, evaluating the scientific accuracy of textbook representations, designing discrepant events, and responding to partially correct explanations. They should also examine their own conceptions using multi-tier or explanation-based instruments. Because a teacher's confident misconception can be more consequential than a student's isolated error, science methods courses should include explicit conceptual diagnosis across the major elementary science domains.

Practical Recommendations

Five practical priorities emerge from the review. First, begin each major science topic with a brief diagnostic task that asks for both an answer and a reason. Second, select concrete phenomena that can test common intuitive explanations. Third, use POE, inquiry, argumentation, or discrepant events to create evidence-based conceptual conflict. Fourth, connect macroscopic observations with diagrams, models, and age-appropriate particle or system explanations. Fifth, reassess the original conception after instruction and require students to explain what changed in their reasoning. At program level, schools and teacher-education institutions should develop banks of validated misconception probes aligned with elementary science topics.

Limitations

This review is narrative rather than systematic, so it does not claim exhaustive coverage of all studies or calculate a pooled prevalence of elementary science misconceptions. The included literature varies in grade level, cultural context, diagnostic instrument, and

criteria for classifying misconceptions. Some studies involve preservice teachers rather than children and are used only to illuminate teacher-related implications. Future research should conduct domain-specific systematic reviews, report item-level diagnostic evidence, and examine whether conceptual change is retained over time and transferred to new contexts.

Conclusion

Misconceptions in elementary science are recurring conceptual structures rather than random mistakes. They are especially common when learners must infer invisible mechanisms, coordinate representations, or replace everyday causal reasoning with scientific models. Evidence across force and motion, matter and heat, photosynthesis, electricity, light, and Earth-space science shows that conventional answer-only assessment is insufficient for valid diagnosis. Reasoning-based and confidence-sensitive approaches provide stronger evidence and help distinguish stable misconceptions from guessing or incomplete knowledge. The most productive instructional responses make prior ideas explicit and require learners to test, explain, and revise them through conceptual-change models, POE, discrepant events, inquiry, argumentation, models, and guided digital representations. For elementary schools, the central implication is practical: diagnosis and remediation should be embedded in routine science teaching. For teacher education, prospective teachers must learn not only correct scientific content but also how to recognize and reconstruct the alternative conceptions that children bring to the classroom.

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Conceptualization, B.E.J.K. and Y.R.; literature analysis, B.E.J.K. and S.M.; methodology, B.E.J.K. and Y.R.; writing-original draft preparation, B.E.J.K.; writing-review and editing, Y.R. and S.M. All authors have read and agreed to the manuscript.

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The authors declare no conflict of interest.

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